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Trace Element Study at a Primary Copper Smelter

Volume II
Report Appendix

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TRACE ELEMENT STUDY AT A PRIMARY COPPER SMELTER

Volume II: Report Appendix

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the findings of an investigation of air pollutant emissions from the reverberatory furnace pollution control system at a primary copper smelter. The study was performed to assess the degree of particulate emissions control and control problems associated with the application of electrostatic precipitators in the nonferrous metals production industry. The results are being used within the Agency's Office of Research and Development as part of a larger effort to define the potential environmental impact of emissions from this industry segment and the need for improved controls. The findings will also be useful to other Agency components and the industry in dealing with environmental control problems. The Metals and Inorganic Chemicals Branch of the Industrial Pollution Control Division should be contacted for any additional information desired concerning this program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This project was undertaken to explore the distribution of trace elements in environmental emissions from a primary copper smelter. The efforts were concentrated on the reverberatory furnace and the electrostatic precipitator controlling emissions from the reverberatory furnace. The following major conclusions were reached: (1) the electrostatic precipitator effectively controls all particulate emissions at its design efficiency rating (about 96%) at the operating gas temperature of 600 degrees F; (2) appreciable material composed of toxic trace elements pass through the precipitator in the vapor state at the ESP operating temperature and condense to form particulate upon cooling. Arsenic trioxide was a major constituent of the emissions passing the ESP from the reverberatory furnace. The following elements were examined: Al, As, Ba, Be, Ca, Cd, Cr, Cu, F, Fe, Hg, Mo, Ni, Pb, Sb, Se, Si, V, Zn.

This report was submitted in fulfillment of Contract No. 68-01-4136 by Radian Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from July 1976 to December 1976, and work was completed as of May 1977.

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SECTION 1

INTRODUCTION

Volume I summarizes all major findings. The present Volume II gives more details concerning sampling, sample analysis and data evaluation.

The primary copper smelter studied in this report started production about 25 years ago. Gas cleaning facilities were added in the early seventies to treat the off-gases from the converters. Waste heat boilers and electrostatic precipitators (ESP) are currently used to generate steam and remove particulates from both reverberatory furnace and converter gas streams. The cleanup and cooling of converter gases is achieved in a humidifier, cooler, wet electrostatic precipitator arrangement followed by a contact sulfuric acid plant.

The primary goal of the present study was to evaluate the performance of the electrostatic precipitator (ESP) collecting particulate matter escaping the reverberatory furnace. Several sampling techniques were chosen to determine:

- gas flow rate,
- gas composition,
- grain loading at the inlet duct,
- grain loading at the outlet duct,
- particle size distribution,
- electrical performance of the ESP,
- trace element material balance,
- trace element flow rates as vapor,
- the amount of material condensible between the gas temperature of 600°F and the EPA recommended cool-off point of 250°F, and
- arsenic emission rates using an EPA suggested sampling device.

The sampling effort was conducted from July 8 through July 16, 1976. A detailed sampling schedule is presented in Table 1-1.

TABLE 1-1. A SUMMARY OF THE SAMPLING EFFORT (JULY 7 THROUGH JULY 16, 1976)

Date	Location/Stream Sampled	Parameter	Technique
Evaluate Reverb ESP performance:			
7-8 to 7-10	ESP Outlet	grain loading	in-stack filter
7-10	ESP Outlet	particle size distribution	Andersen cascade impactor (SRI)
7-8 to 7-10	ESP Inlet	grain loading	instack filter
7-10	ESP Inlet	particle size distribution	Brinks cascade impactor (SRI)
7-10	ESP Control Room	electrical performance	monitor operating parameters (SRI)
Complete a material balance around Reverb ESP:			
7-11	ESP Outlet	trace element flow rates	integral WEP
7-11	ESP Inlet	trace element flow rates	integral WEP
7-11 to 7-13	ESP Dust	trace element flow rates	periodic grab sample
Complete an approximate material balance around the Reverb furnace:			
7-13	ESP Outlet	trace element flow rates	integral WEP
7-12 to 7-14	Reverb feed	trace element flow rates	compositing slinger bin catches at the end of each shift
7-11 to 7-13	ESP Dust	trace element flow rates	periodic grab sample
7-12 to 7-14	Reverb Slag	trace element flow rates	periodic grab sample
7-12 to 7-14	Matte	trace element flow rates	periodic grab sample
Collect particulate by particle size for trace element analysis:			
7-16	ESP Outlet	particulate by size fraction	3 out of stack cyclones in series plus filter
Collect vapor phase emissions:			
7-16	ESP Outlet	trace element flow rates as vapor	filter at duct temperature followed by impingers
Determine amount of condensible material and SO_x emitted:			
7-15	ESP Outlet	condensed material (between 600°F-250°F) and SO_2-SO_3 concentrations	EPA 5 train with in-stack filters
7-15	ESP Outlet	condensed material (between 600°F-250°F) and SO_2- SO_3 concentrations	EPA 5 train with in-stack filters
Determine arsenic emission rates:			
7-13 to 7-14	ESP Outlet	arsenic emission rate	modified EPA Method 5 train
7-13 to 7-14	ESP Inlet	arsenic emission rate	modified EPA Method 5 train

Plant management released composites of the following samples:

- concentrate (reverberatory furnace feed),
- matte, and
- reverberatory furnace slag.

In addition, all critical flow rates were released to Radian. A complete material balance around the reverberatory furnace was still not possible because compositions for the following streams are not known:

- converter slag
- dust collected in the converter waste heat boiler, the balloon flue, and the converter ESP, and
- material condensed on the surface of the reverberatory furnace waste heat boiler.

The main findings of the study are presented below.

SMELTER MINOR ELEMENT FLOW

1) Titanium, potassium, magnesium, and sodium enter the smelter as major components besides the elements of importance in the smelting operation itself (Cu, Fe, Si, Ca, and Al).

2) Minor elements of environmental concern are:

- arsenic,
- cadmium,
- molybdenum,
- lead,
- antimony,
- selenium,
- zinc, and
- fluorine.

3) The rest of the elements surveyed enter in the low ppm concentration range or were not detected by spark source mass spectrometry analysis.

4) Molybdenum entering the reverberatory furnace with the concentrate is almost completely discharged in the reverberatory furnace slag.

5) Nearly 50 percent of the selenium and 30 percent of the fluorine are discharged together with the reverberatory furnace off-gases.

6) Nearly all of the fluorine escapes in the gaseous state.

ARSENIC SAMPLING

The arsenic flows found by Radian have been repeated by Smelter personnel during the periods of February 28 through March 4, 1977. In addition, integral arsenic balances were established for the months of January and March 1977. The findings are incorporated in this report.

1) Approximately 50 percent of the arsenic entering the smelter leaves in the reverberatory furnace off-gas based on both plant and Radian sampling data.

2) Data gathered during this study indicate that as much as 90 percent of the arsenic entering the reverberatory furnace ESP may leave with the off-gas.

3) Arsenic and selenium escaping the electrostatic precipitator are partly in the vapor state.

4) The arsenic concentration in the reverberatory furnace feed varies within a few days from 700 ppm to 7000 ppm. This variation is not only a function of the arsenic concentration in the ore, but also depends on the amount of electrostatic precipitator dust recycled.

5) The following arsenic rates were determined at the ESP outlet:

140 lb/hr - July 11, 1976 - Radian, direct measurement
76 lb/hr - July 13, 1976 - Radian, direct measurement
54 lb/hr - July 13, 1976 - Radian, direct measurement
45 lb/hr - July 14, 1976 - Radian, direct measurement
51 lb/hr - July 14, 1976 - Radian, direct measurement
45 lb/hr - January, 1977 - Smelter, balance difference
40 lb/hr - March, 1977 - Smelter, balance difference
25 lb/hr - March 1, 1977 - Smelter, direct measurement
34 lb/hr - March 2, 1977 - Smelter, direct measurement
49 lb/hr - March 3, 1977 - Smelter, direct measurement

6) The arsenic detected was present as arsenolite, As_2O_3. This was determined by X-ray diffraction.

ESP PERFORMANCE

1) ESP temperature (600°F) and gas flow rate (160,000 acfm) correspond to design parameters.

2) ESP inlet grain loading determined at duct temperature is 0.60 grains/scf, and the outlet grain loading is 0.020 grains/scf. The overall particulate collection efficiency is calculated to be 96.7%. Design efficiency was 96.8%.

3) The amount of condensibles between duct temperature 600°F and 250°F (EPA recommended) accounts for material corresponding in mass to an additional 1.60 grains/scf at the inlet and 1.0 grains/scf at the outlet.

4) The element flow at the reverberatory furnace ESP outlet measured July 11, 1976 is as follows:

Sulfur	2260	lbs/hr
Arsenic	140	lbs/hr
Fluorine	7.8	lbs/hr
Copper	1.0	lbs/hr
Selenium	0.97	lbs/hr
Antimony	0.33	lbs/hr
Molybdenum	0.2	lbs/hr
Nickel	0.1	lbs/hr
Lead	0.1	lbs/hr
Zinc	0.1	lbs/hr

5) Good material balance closure around the ESP was established for:

Arsenic	Nickel
Beryllium	Sulfur
Chromium	Antimony
Copper	Selenium
Fluorine	Vanadium
Mercury	Zinc
Molybdenum	

The balance for cadmium is marginal. The balance for barium and lead did not close due to precipitation of insoluble sulfates in the collection device.

6) Cadmium, lead, and zinc entering the smelter are transported with the matte to the converters. Cadmium most likely leaves the smelting circuit with the converter off-gases. Some of the zinc and lead will be volatilized in the converter. Some will also be returned to the reverb in the converter slag.

The study was performed in parallel with an effort by Southern Research Institute, Birmingham, Alabama (SRI). SRI determined the electrical characteristics of the ESP during the sampling period and also determined the particle size distribution at the inlet and outlet using Brink's impactors. Details of these investigations can be found in SRI's report: "Performance Evaluation of an Electrostatic Precipitator Installed on a Copper Reverberatory Furnace," SORI-EAS-76-511, EPA Order #CA-6-99-2980-J.

The following sections present the detailed results of this study. The important conclusions were summarized in Volume I. A general plant description and a more detailed discussion of the reverberatory furnace are presented in Section 2. Sections 3 through 15 discuss the sampling and analytical procedures. The results of individual sampling efforts are included in these sections.

SECTION 2

PLANT DESCRIPTION

This section first covers the material flow in the smelter. The reverberatory furnace, the hot electrostatic precipitator and the plant operation during sampling are described next.

MATERIAL FLOW

The copper smelting facility sampled can be divided into the following process steps (see Figure 2-1):

- mining,
- concentrate preparation,
- reverberatory furnace feed preparation,
- matte production in the reverberatory furnace,
- reverberatory furnace off-gas cleaning by hot electrostatic precipitation,
- production of blister copper in the converters and copper refining in the anode furnace, and
- cleaning of the converter off-gases with sulfuric acid production.

An open pit mine feeds the smelter. Typical copper concentrations in the ore range from 0.5 to 1.0%. All ore with less than 0.3% copper content is rejected as waste rock.

The flow of the copper ore is depicted in Figure 2-2. Several trains transport the ore from the mine to the crushing and grinding unit. The first step is the reduction of the larger boulders in a gyratory crusher. Next, continuous reduction of the rock size is achieved in cone crushers. The final step in size reduction of the ore occurs in wet ball mills.

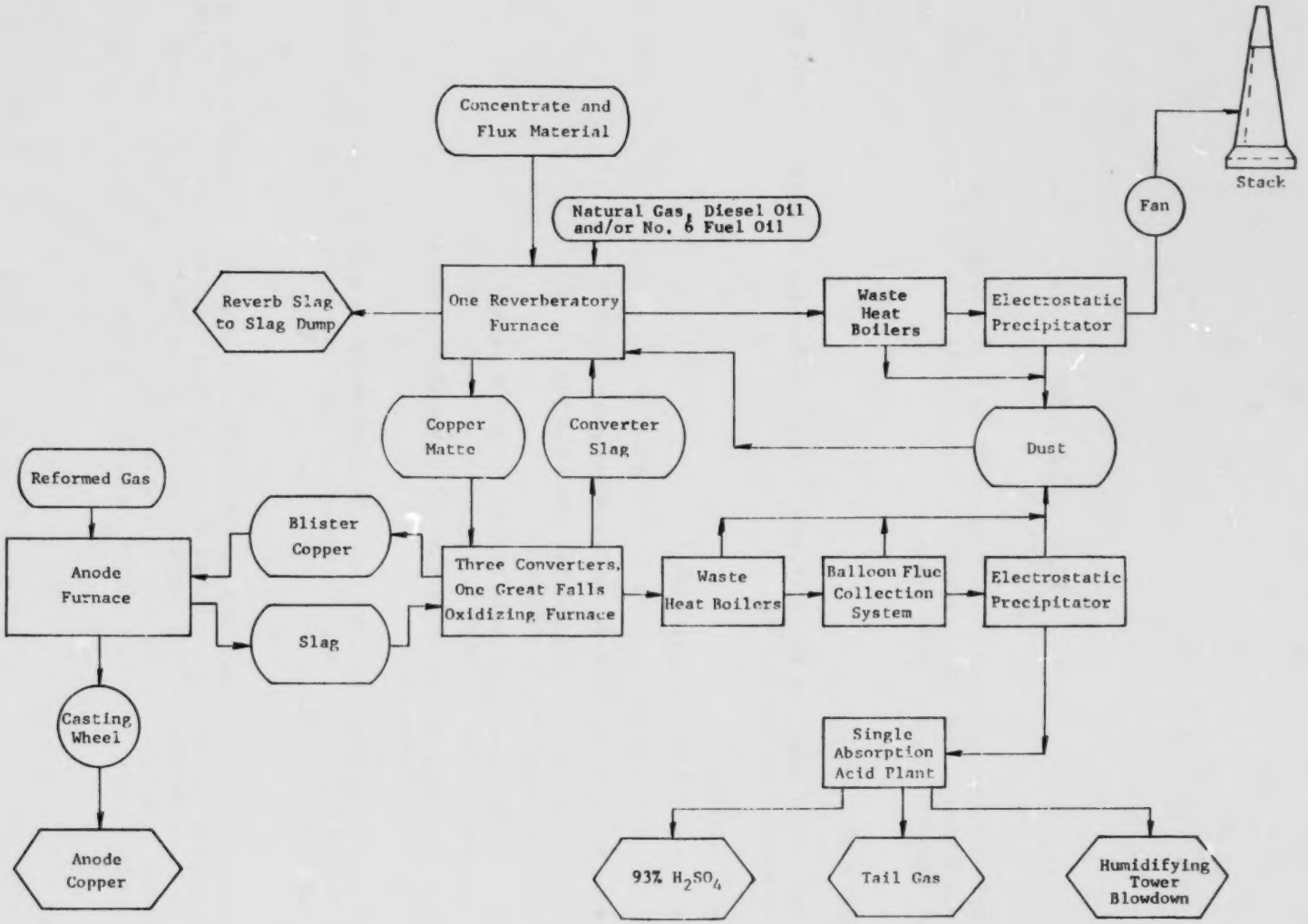


Figure 2-1. Schematic Diagram of Primary Copper Smelter.

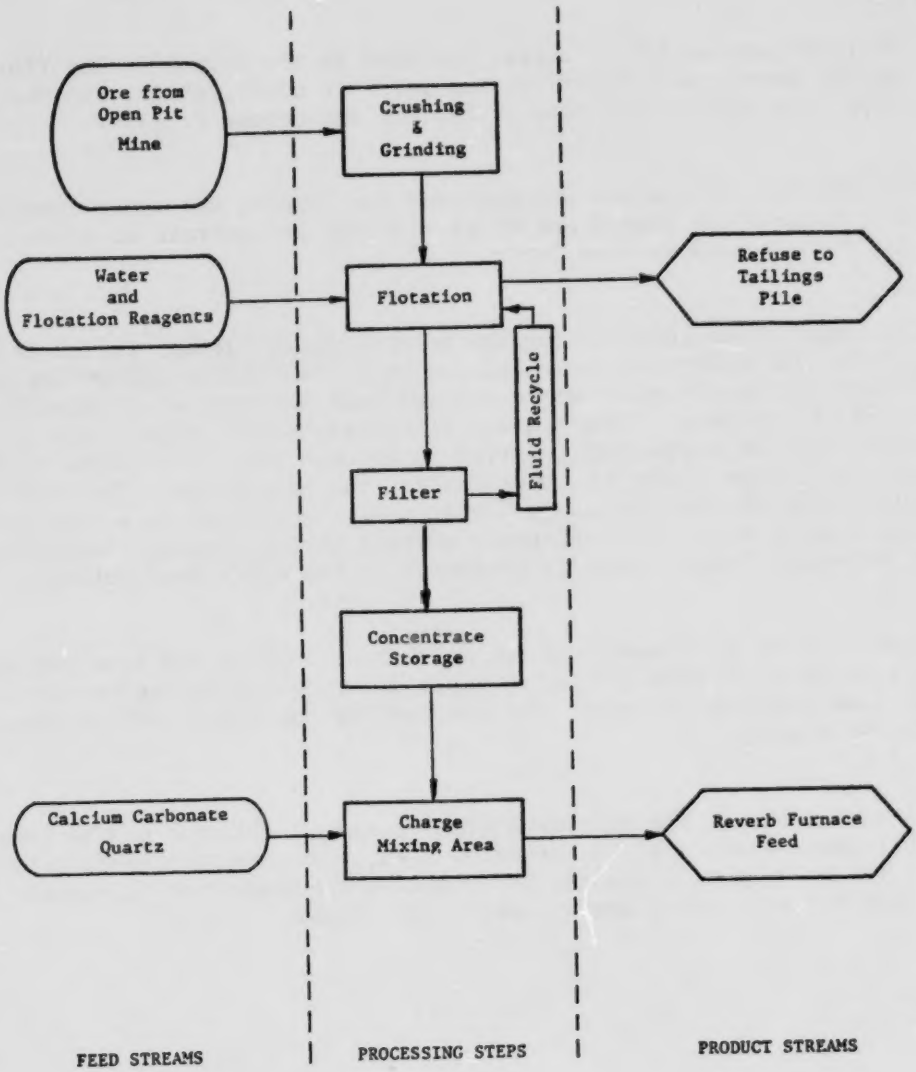


Figure 2-2. Reverberatory Furnace Feed Preparation.

Water and flotation reagents are added to the ball mill effluent stream and the slurry is aerated. Copper bearing particles adhere to the ascending air bubbles. The "froth" is skimmed from the surface. Solid-liquid separation is achieved next by vacuum filtration. The aqueous phase is recycled, and the concentrate containing 20% or more copper goes to storage.

The particulates low in copper ore sink to the bottom in the flotation step and are pumped as a slurry to the tailings pond. Again, supernatant water from this pond is recycled to the ore enrichment facility.

The ore and concentrate are analyzed for copper, and major constituents. Calcium carbonate and quartz are mixed with the concentrate to produce an optimum reverberatory furnace feed.

The major steps in operating the reverberatory furnace are shown in Figure 2-3. The purpose of this furnace is to reduce the sulfur and iron in the concentrate to the point where FeS and Cu_2S are present in approximately stoichiometric amounts. This mixture is called matte. Excess iron sulfide is converted in an exothermic reaction to FeO and SO_2. Iron oxide combines with silica to form a slag of lower density than the matte. The slag layer is removed from the reverberatory furnace and transported in a slag train to the slag dumping site. The off-gases contain sulfur dioxide, particulate matter and metal fumes. Heat is recovered in two waste heat boilers.

Particulates are removed in two waste heat boilers and in a hot electrostatic precipitator. The collected dusts are recycled to the reverberatory furnace feed preparation area. The gas leaving the reverb ESP is discharged through the stack.

Streams entering the reverberatory furnace in addition to the concentrate (reverb furnace feed) are (1) converter slag, (2) converter dusts collected in both the balloon flue and the ESP treating the converter off-gases, and (3) reverb ESP and reverb waste heat boiler dusts.

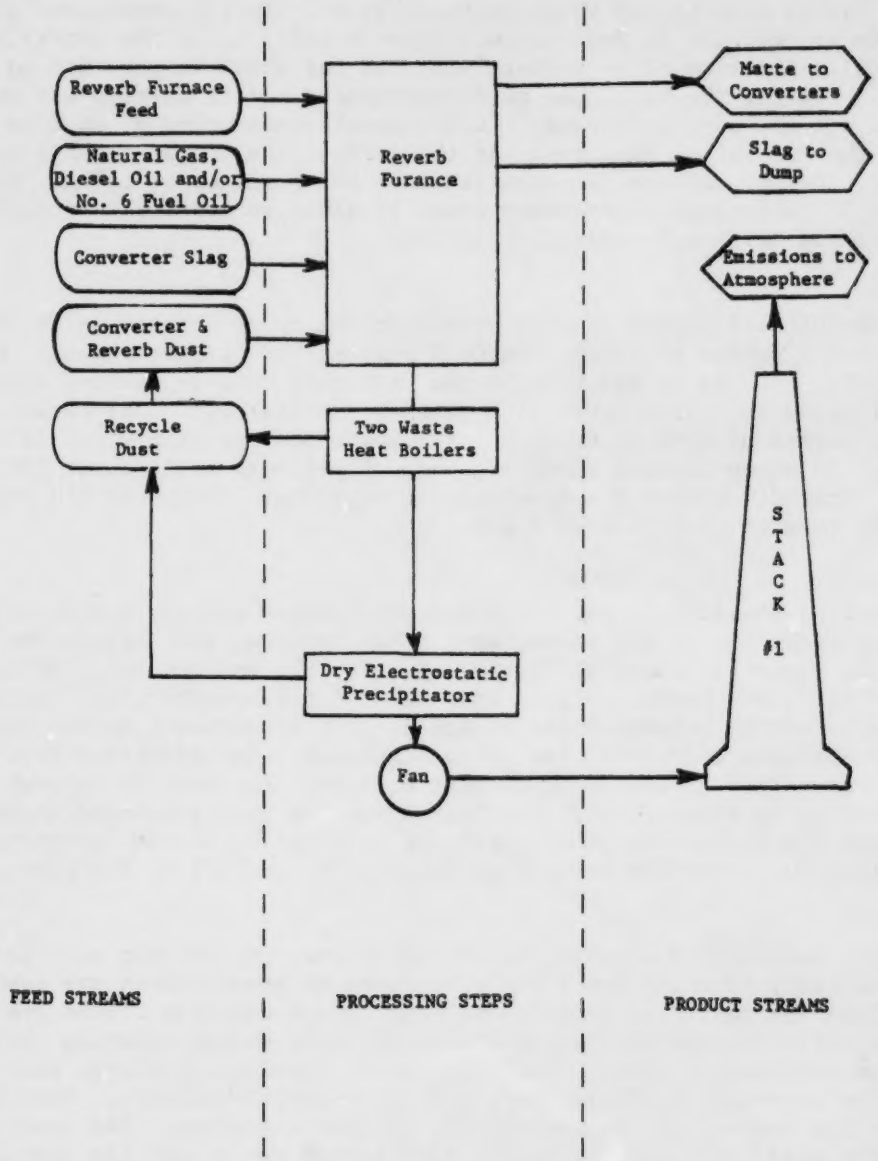


Figure 2-3. Reverberatory Furnace Flow Diagram.

Three Pierce-Smith converters process the matte produced in the reverberatory furnace. The schematic of the material flow is shown in Figure 2-4. Charging of the matte to the converters is a batch process using ladles transported by an overhead crane. In the converter, iron sulfide is oxidized to FeO and SO_2. Quartz addition to the converter binds the FeO in the form of a silicate slag (4% Cu) which is recycled to the reverb. Again, the operation is discontinuous and is carried out using ladles and the overhead crane. "White metal" consisting of Cu_2S is left after the removal of the iron. At this stage, the copper blowing cycle starts. Copper sulfide is converted to a 98% pure copper called "blister copper." Cold copper-containing scrap is added periodically to absorb the heat of the exothermic overall reaction.

The blister copper is transported to the anode furnace using ladles. Air blowing serves to remove the Cu_2S left in the blister copper. Copper containing Cu_2O as an impurity is the result of this processing step. The copper oxide is then reduced with reformed natural gas. The resulting copper with a purity of 99+% is ready for the anode pouring step which is done once a day. An anode casting wheel is used. The anodes weigh about 750 lbs apiece and are shipped for electrolytic refining. Output of the plant is 180-200 tons of anode copper a day.

Sulfur dioxide off-gas, dust and metal fumes are the result of the Cu_2S and FeS oxidation in the converters. The converter dust collection and gas cleaning steps are shown in Figure 2-5. The SO_2 concentration of the converter off-gases is much higher than that of the reverberatory furnace and typically varies between 4 and 8% and as such is amenable to the manufacturing of sulfuric acid using the contact process. The off-gases from the converter are first cooled in waste heat boilers. Particulate removal is achieved in an electrostatic precipitator. The dust collected in the balloon flue and the electrostatic precipitator is recycled to the reverberatory furnace. Dust from the waste heat boilers is fed back to the converters.

Gas cooling and cleaning is the first step in sulfuric acid production. A humidifier, a cooler and a wet electrostatic precipitator are used to cool and clean the gas. The humidifying tower has a blowdown stream consisting of dilute sulfuric acid containing the particulate matter escaping the ESP, as well as condensable fumes. The H_2SO_4 plant consists of drying towers, a vanadium pentoxide catalytic bed, and SO_2 absorption towers. Heat exchangers remove the heat of the exothermic SO_2 oxidation process. The product of the sulfuric acid plant is a 93% H_2SO_4 acid stream and a tail gas with low concentrations of contaminants.

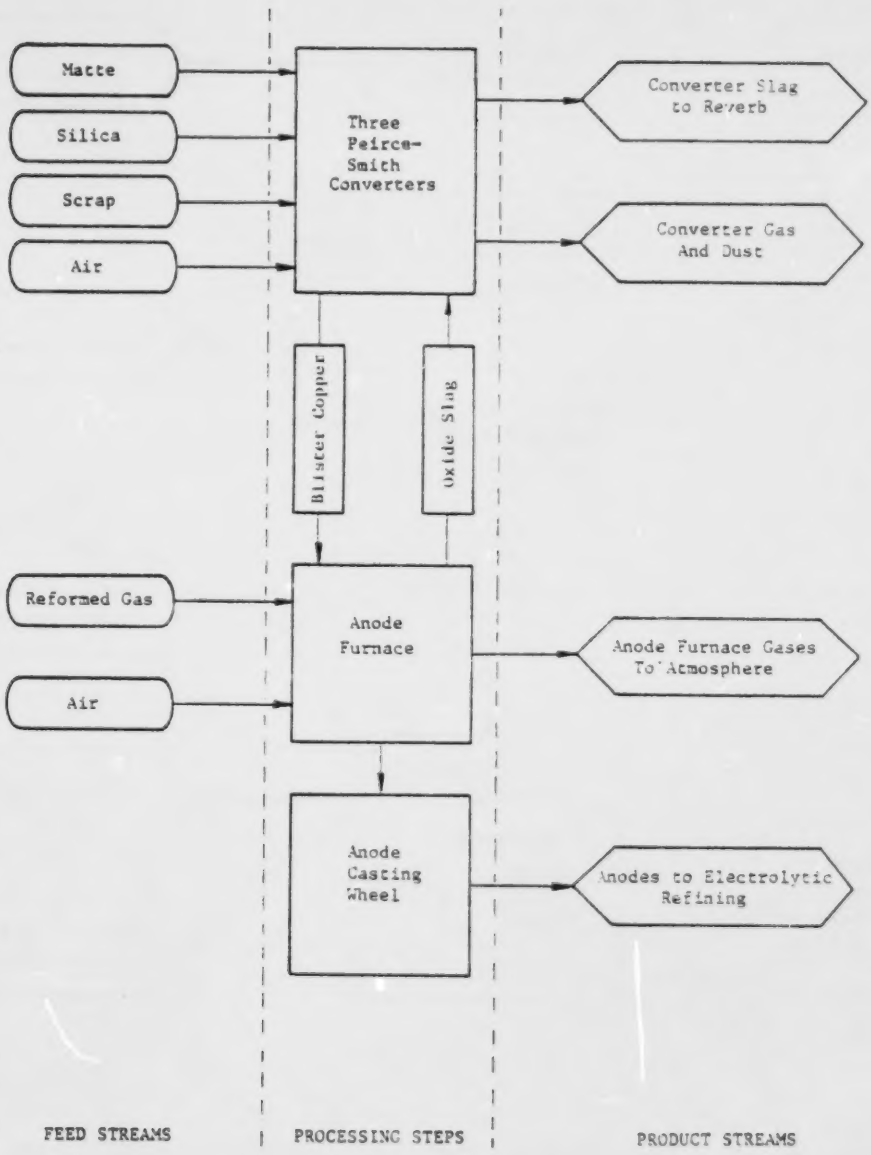


Figure 2-4. Converters and Anode Furnace.

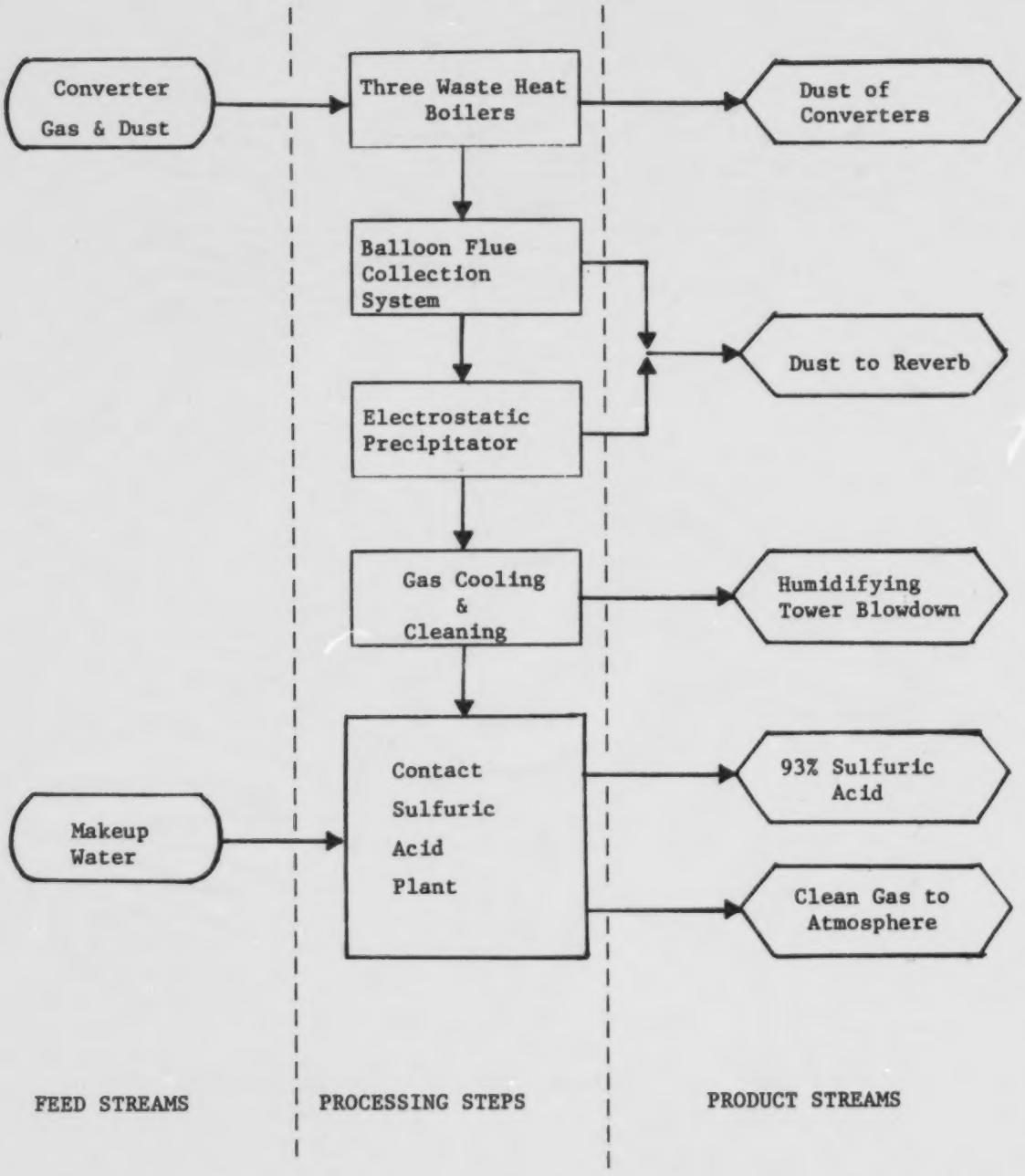


Figure 2-5. Converter Dust Recovery and H_2SO_4 Plant.

REVERBERATORY FURNACE

The single reverberatory furnace, 30 feet wide and 100 feet long (inside dimensions), fired with burners which are capable of burning natural gas, diesel oil and/or No. 6 fuel oil, processes concentrates from the milling and flotation plant. The concentrates, which comprise over 90% of the furnace charge are received from the filter plant and dryer by conveyor or from stock piles by truck. Each charge is weighed on scales and is carried by overhead crane to a charge point above and to the side of the furnace. Six charge ports are provided, three on each side of the furnace. A concrete bin of approximately 1600 tons capacity is used for surge storage of concentrates. When necessary, the concentrates are reclaimed by clamshell from the storage bin.

The bath smelting reverberatory furnace was designed for wet smelting. The crucible of the furnace is constructed in sections of rammed periclase. The top and sides of the furnace crucible are cooled by copper water jackets. The working bottom of the furnace is magnetite accretions fused in place. The bath smelting furnace requires reaction between the new charge and the liquid bath to cause spreading of the new charge. When calcines are smelted, charging them through an inclined pipe imparts sufficient velocity to allow a reaction with the liquid bath to cause spreading of the new charge. This gravity charging method cannot be used with wet concentrates, however, since they will not flow through an inclined pipe as will calcines. Considerable research was necessary to develop proper charging equipment. It is necessary to charge the wet concentrates to the furnace at a considerable velocity and at a relatively flat angle. This enables the wet concentrate to penetrate the liquid bath sufficiently to start the spreading reaction and prevents the concentrate from piling up in one place.

A high-speed belt slinger was developed for this operation and has performed well. Six slingers are provided, three on each side of the furnace. Each has a port through the sidewall covered with a vertically movable door when not in use. When charging begins, the door is raised by an air cylinder, the slinger started, and the concentrates drop onto the slinger from the charge can overhead. The slinger angle is adjustable both horizontally and vertically. Belt speeds are variable allowing the charging rate to range from 1.5 to 2 tons/min for each slinger. Furnace charging is done by one man and is controlled by visual inspection.

The reverb is of the sprung silica arch type. The brickwork is maintained by silica slurry hot patching. The silicious material of over 90% SiO_2 is ground wet in a ball mill and pumped to a storage tank above the furnace from which it is blown and sprayed onto the interior surface of the brickwork. A curtain damper has been used successfully in the furnace and its use has resulted in better working conditions and decreased maintenance expense in and around the boiler uptakes and flues. The curtain damper

sections are made of cast refractory supported by loops of water-cooled steel tubing and are maintained by slurry patching.

REVERBERATORY FURNACE ESP

Gases from the reverberatory furnace enter two waste heat boilers in parallel. The boilers cool the gas to approximately 600°F and remove some particulate and condensable material. Steam produced by the boilers is used to generate either electricity or low-pressure air for the converters. Gases exiting the waste heat boiler enter a plenum chamber for mixing prior to treatment in an electrostatic precipitator (ESP).

The reverberatory furnace electrostatic precipitator consists of two independent horizontal parallel units designed to handle a total 160,000 acfm (600°F and 13.8 psia). Gas treatment time is 6 seconds; pressure drop across the precipitator is 0.5 inches w.c. maximum. Collecting surfaces are plates; the discharge electrodes are spring steel wires. The transformer-rectifiers are silicon full wave for 45KV (DC) average; there is an automatic voltage control system to maintain the optimum precipitator operating efficiency. Dust collected is transported via screw conveyor and chain drag to a storage bin from which it is pneumatically conveyed to the charge mixing area for the reverberatory furnace by a fluid flow automatic pump. This pump can handle 20,000 pounds per hour when supplied with 280 scfm compressed air at 30 psig. The electrostatic precipitator and dust handling system are shown schematically in Figure 2-6.

An induced draft fan was installed to draw the reverberatory gases from the reverberatory furnace through the waste heat boilers, the flue system, and the electrostatic precipitator. This fan can handle 160,000 acfm @ 600°F with a suction of -1.75" H_2O and a discharge of 3.25" H_2O. All of the gases can be discharged to the 360-foot concrete stack or part of the gases can go to the stack and part to the SO_2 absorption plant. A remotely controlled damper in the flue going to the stack controls the total volume of gas removed from the reverberatory furnace and the distribution of the gas. The SO_2 absorption plant did not operate during the sampling period.

PLANT OPERATION DURING SAMPLING

The reverberatory furnace operated continuously during the entire sampling program. One upset in the ESP operation was recorded on July 12. This upset was attributed to wet concentrate charged to the furnace. The concentrate dryer was repaired that day and no further upsets were recorded. High dust loadings were noted during the periods when the reverberatory furnace was being charged. This, however, is normal operation.

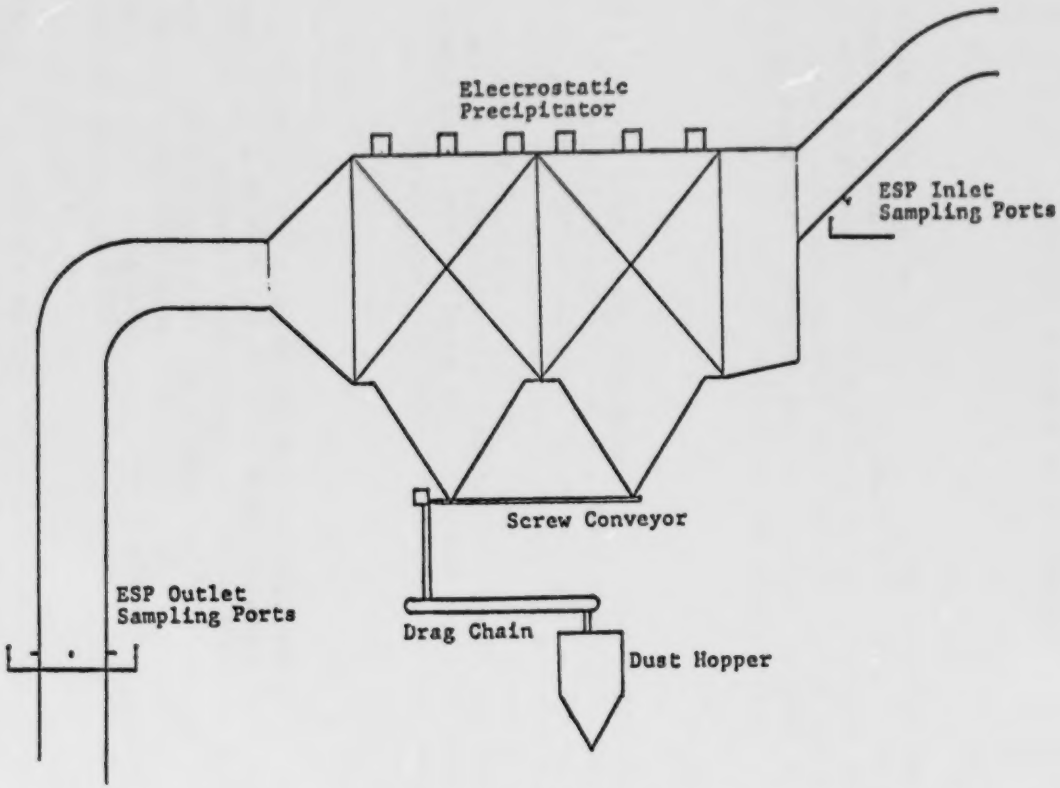


Figure 2-6. Electrostatic Precipitator and Dust Handling System for Reverberatory Furnace Gases.

SECTION 3

DESCRIPTION OF SAMPLING POINTS

PRECIPITATOR INLET

The duct configuration at the inlet is depicted in a three-dimensional sketch, Figure 3-1. Both the west and the east ducts are 4 feet deep and 6 feet wide. Each of them is equipped with six 3-inch sampling ports with male threads. The angle between the vertical faces of the mixing chamber and the incoming duct is slightly smaller than 135 degrees. The sampling ports are accessible from two platforms, each 6 ft by 6 ft.

PRECIPITATOR OUTLET

The sampling conditions at the outlet duct are almost ideal. A three-dimensional sketch of the sampling location is shown in Figure 3-2. The outlets of the two ESP's join far enough upstream of the sampling ports that uniform flow and particle distribution can be expected. The diameter of the common duct is six feet. Three sample ports are provided three feet above the sampling platform. The south and west port are three inches and the north port is four inches in diameter. All sampling ports have female threads in contrast to the inlet ports which have male threads.

PRECIPITATOR DUST

Dust collected in the electrostatic precipitators is conveyed to a storage bin by a screw conveyor and a chain drag. From here it is transported back to the charge mixing area of the reverberatory furnace by a fluid flow automatic pump. The rating of the pump is 20,000 pounds per hour. Operation of the pump is intermittent. Individual samples were conveniently obtained through a port on top of the chain drag. An integral sample could then be accumulated during the sampling periods at the inlet and outlet ducts.

Measurements of the dust level in the storage bin were made by using a chain-secured bucket. The storage bin was emptied prior to the sampling run. The bucket was lowered periodically through the port on top of the storage bin to measure the dust level. The dimensions of the storage bin were obtained from blueprints. This allowed the mass of dust accumulated to be calculated from the average level increase, the dust density and the

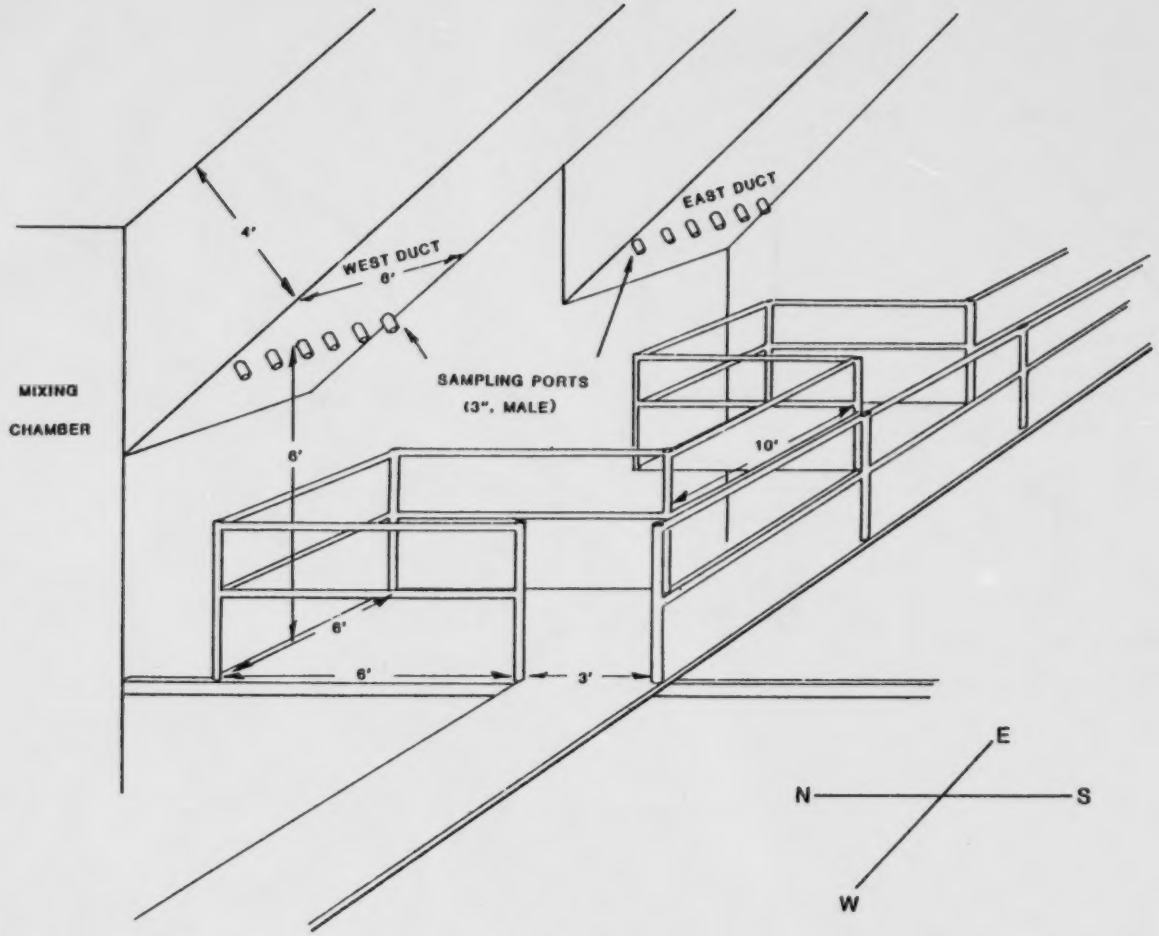


Figure 3-1. Schematic Diagram of Inlet Ducts.

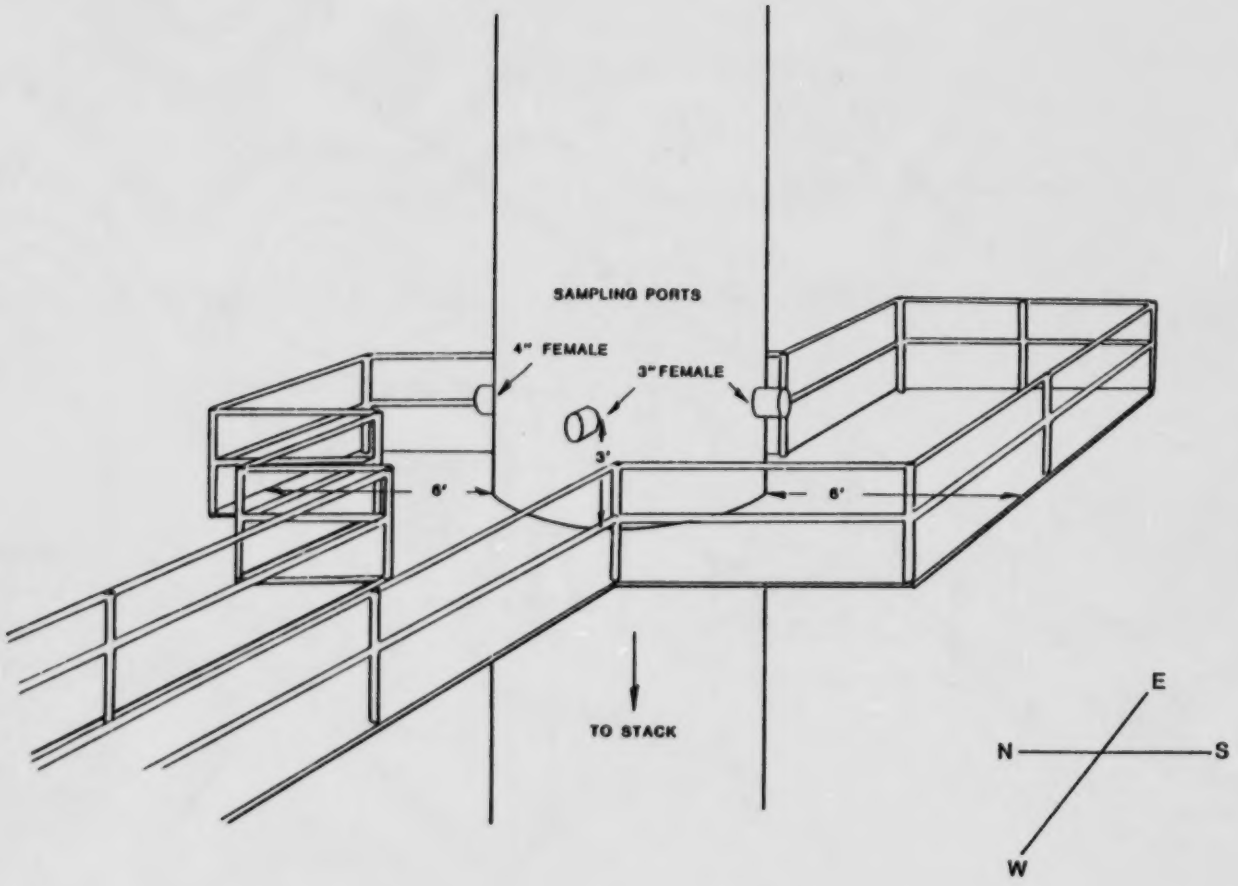


Figure 3-2. Schematic Diagram of Outlet Duct.

storage bin dimensions. Dust flow rates determined in this fashion varied widely. A flow rate obtained by difference of the grain loading at the ESP inlet and outlet was therefore used for the material balance calculations.

CONCENTRATE

The furnace is charged with concentrate by slingers. A small amount of concentrate adheres to the slinger belt during charging. To prevent this material from being scattered in the furnace work area, bins the width of the belt are placed so that they catch this small amount of concentrate. The bins are emptied at the end of each shift; the combined catch from all six slingers is 100-200 pounds. An integral concentrate sample was obtained by emptying the bins into a barrel at the end of the shift. A representative sample was taken from the barrel, thus giving a concentrate sample which was made up of concentrate from each of the six slingers integrated over the duration of the shift.

MATTE AND SLAG

Smelter personnel routinely sample the furnace matte and slag for analysis to provide operational data. Composite samples from each shift of these two streams were provided by the plant for July 12 through 14. These were a portion of their routine samples.

Converter slag and recycle dust from the converter waste heat boilers, the converter balloon flues and the converter ESP could not be obtained. A complete material balance around the reverberatory furnace was, therefore not possible.

SECTION 4

SAMPLING PROCEDURES

The location and configuration of the ESP inlet sampling ports were described in Section 3. The cross sections of both inlet ducts (east and west) at the test plane were divided into 18 equal area segments designated as shown in Figure 4-1 and 4-2. The characterization of a given parameter for the inlet gas stream can be expressed as the average of that parameter for each of the 36 equal area segments. The selection of 36 points for the inlet test plane was made based on:

- the expected poor flow distribution caused by the immediate termination of the two ducts into the mixing chamber, and
- the number of existing sampling ports.

EPA criteria as documented in Method 1, however, could not be met.

Off-gas exiting the precipitator was sampled from the single 6-foot circular outlet duct. The location and configuration of sampling ports were described earlier. The gas flow is downward and there are no disturbances up or downstream of the test plane close enough to cause an uneven flow distribution. For the precipitator outlet, the cross section of the duct was divided into 12 equal area segments, the center of each area being a sampling point. The sampling points and their designation are shown in Figure 4-3.

EVALUATION OF THE PRECIPITATOR PERFORMANCE

The measurements and equipment listed in Table 4-1 were used to collect data for an evaluation of the electrostatic precipitator. Each of the experiments performed as a part of the characterization is described in subsequent chapters.

Temperature-Velocity

Initial velocity and temperature traverses were made on July 7 using S-type pitot tubes and thermocouples for both inlet ducts and at the outlet.

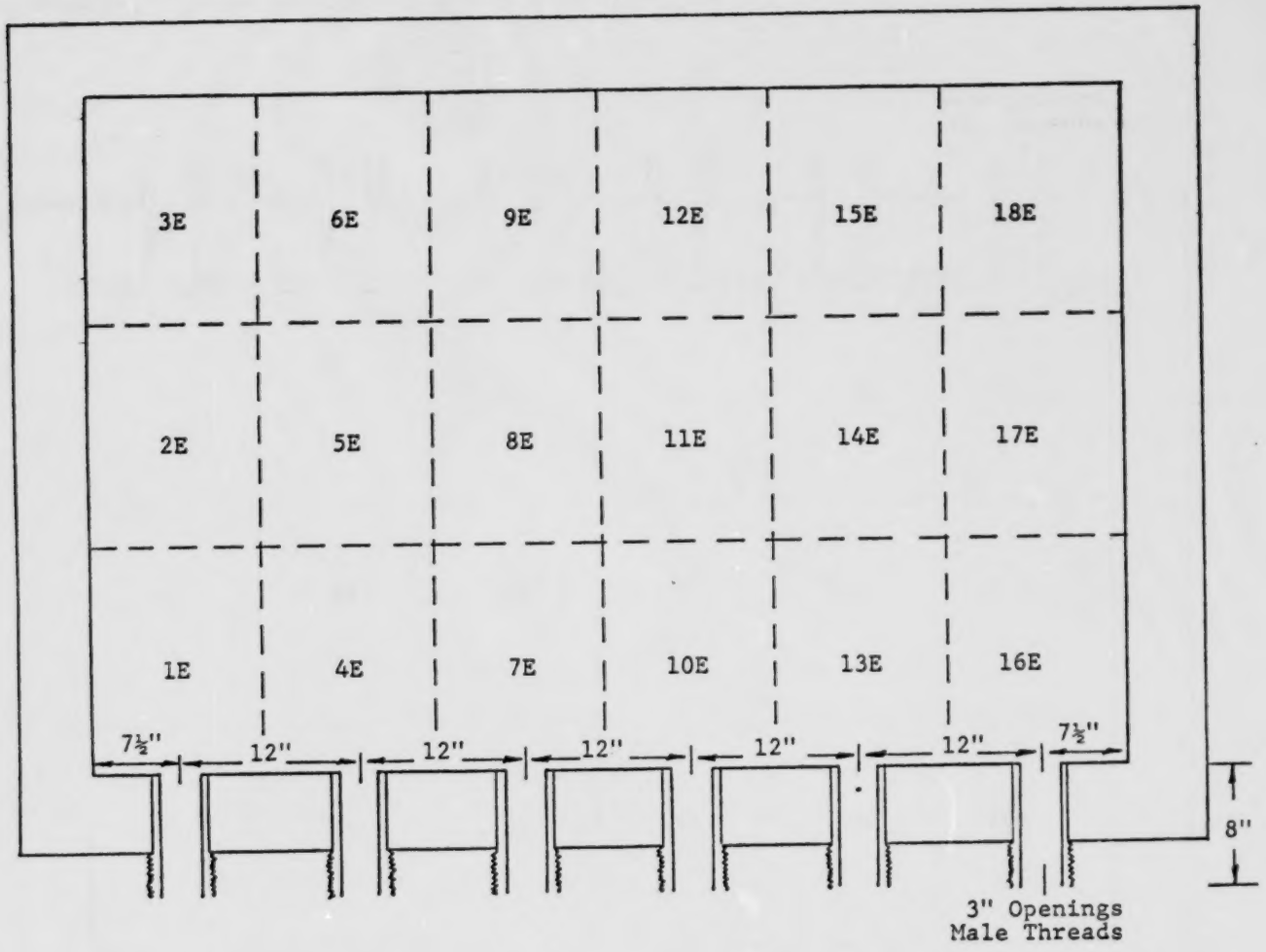


Figure 4-1. Cross Section and Sample Point Identification of East Duct at ESP Inlet.

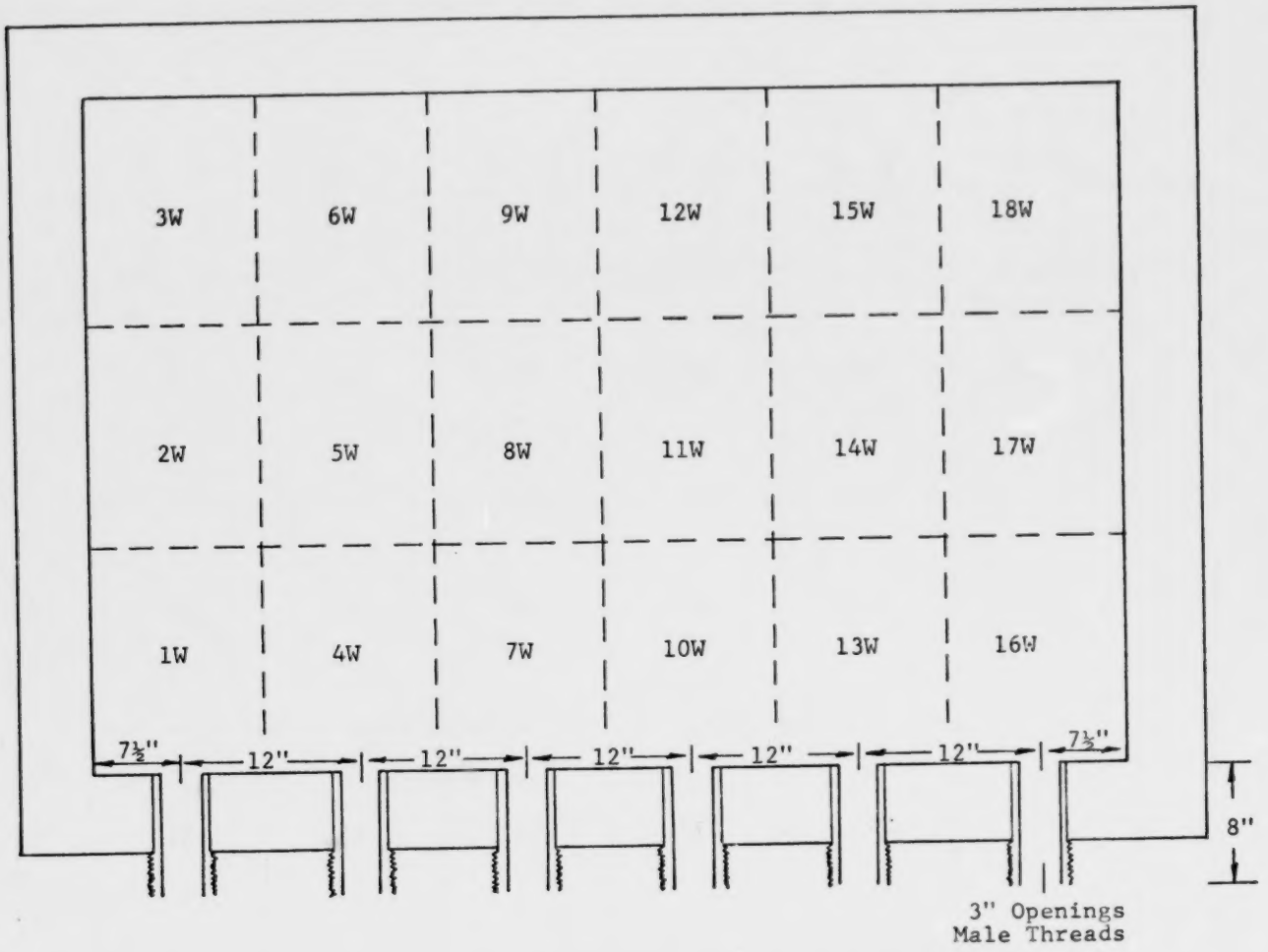
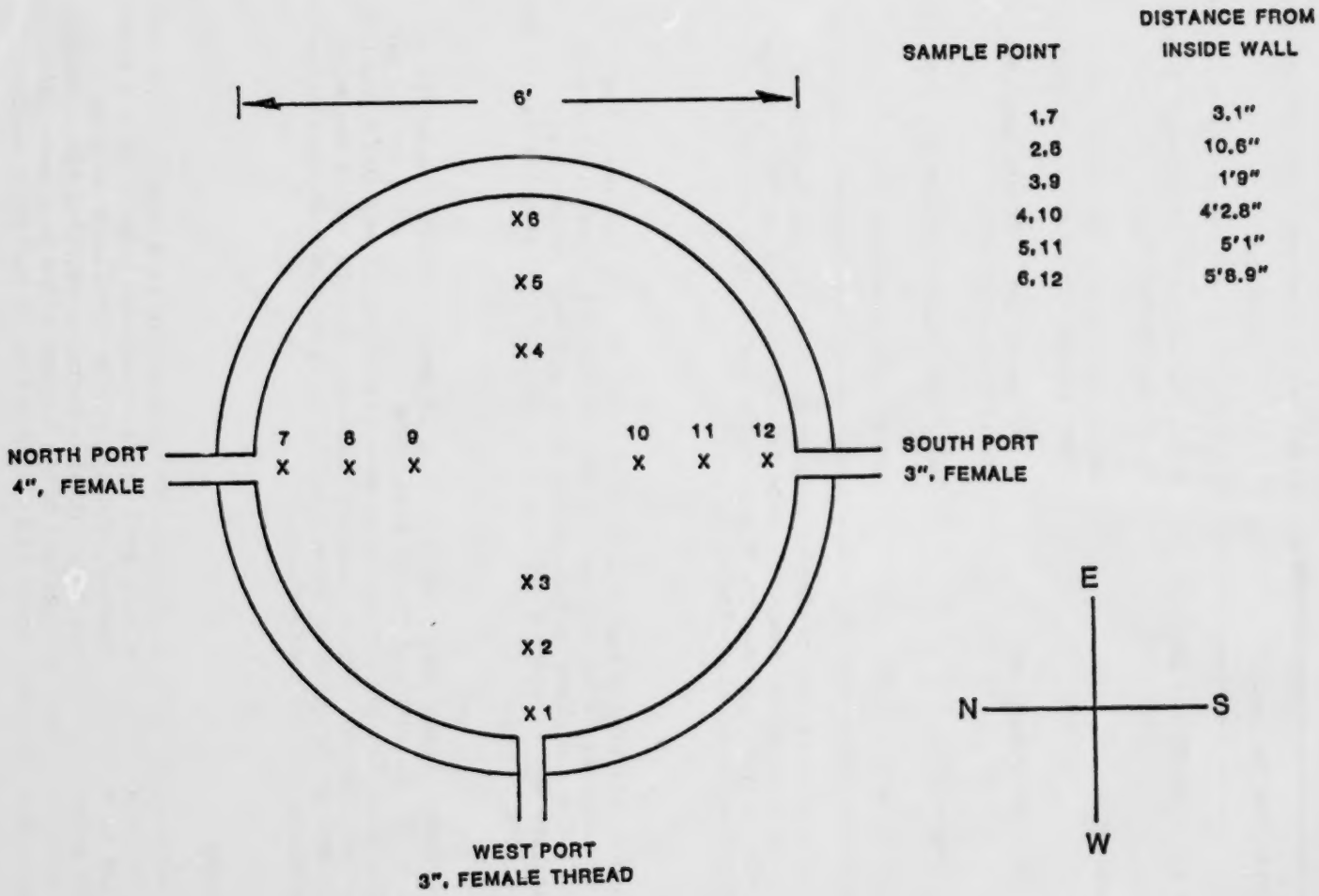


Figure 4-2. Cross Section and Sample Point Identification of West Duct at ESP Inlet.



SAMPLE POINT	DISTANCE FROM INSIDE WALL
1,7	3.1"
2,8	10.6"
3,9	1'9"
4,10	4'2.8"
5,11	5'1"
6,12	5'8.9"

Figure 4-3. Cross Section and Sample Point Identification in Exit Duct.

TABLE 4-1. EQUIPMENT USED FOR MONITORING PRECIPITATOR PERFORMANCE

Parameter Monitored	Equipment
Velocity and temperature profile	Inlet and outlet: calibrated S-type pitot and thermocouple
Grain loading	Inlet and outlet: in-stack glass-fiber filter, followed by impingers
Particle size distribution*	Inlet and outlet: Brinks cascade impactor used in-stack
Flue gas composition	Inlet and outlet: Orsat gas analyzer
Resistivity of precipitator dust*	Resistivity electrode set

* These measurements were performed by personnel of the Southern Research Institute, Birmingham, Alabama. Results are described in "Performance Evaluation of an Electrostatic Precipitator Installed on a Copper Reverberatory Furnace". (SORI-EAS-76-511)

This data provided preliminary information about the gas streams. The velocity profiles as determined on the 7th for the inlet east, inlet west and outlet ducts are shown in Figure 4-4, 4-5, and 4-6, respectively. The temperature and velocity traverses were repeated periodically during the sampling effort.

Measurements taken July 9 through July 10 gave an average velocity at the inlet of 57 fps west and 55 fps east. The average velocity at the outlet was 114 fps. The gas temperatures were 633°F (inlet) and 598°F (outlet) during the same period. These velocity measurements were used along with the grain loadings measured on July 9 and 10 to calculate mass flow rates used to evaluate the ESP performance.

Grain Loading

The particulate grain loading was determined for each duct. Determinations at the inlet were initially made using an alundum thimble with a glass-fiber filter as a backup. However, the use of the thimbles even when packed with glass wool did not significantly increase sampling times before plugging occurred. Thus, all grain loading determination were made using only Gelman class A/E glass-fiber filters housed in 47 mm filter holders.

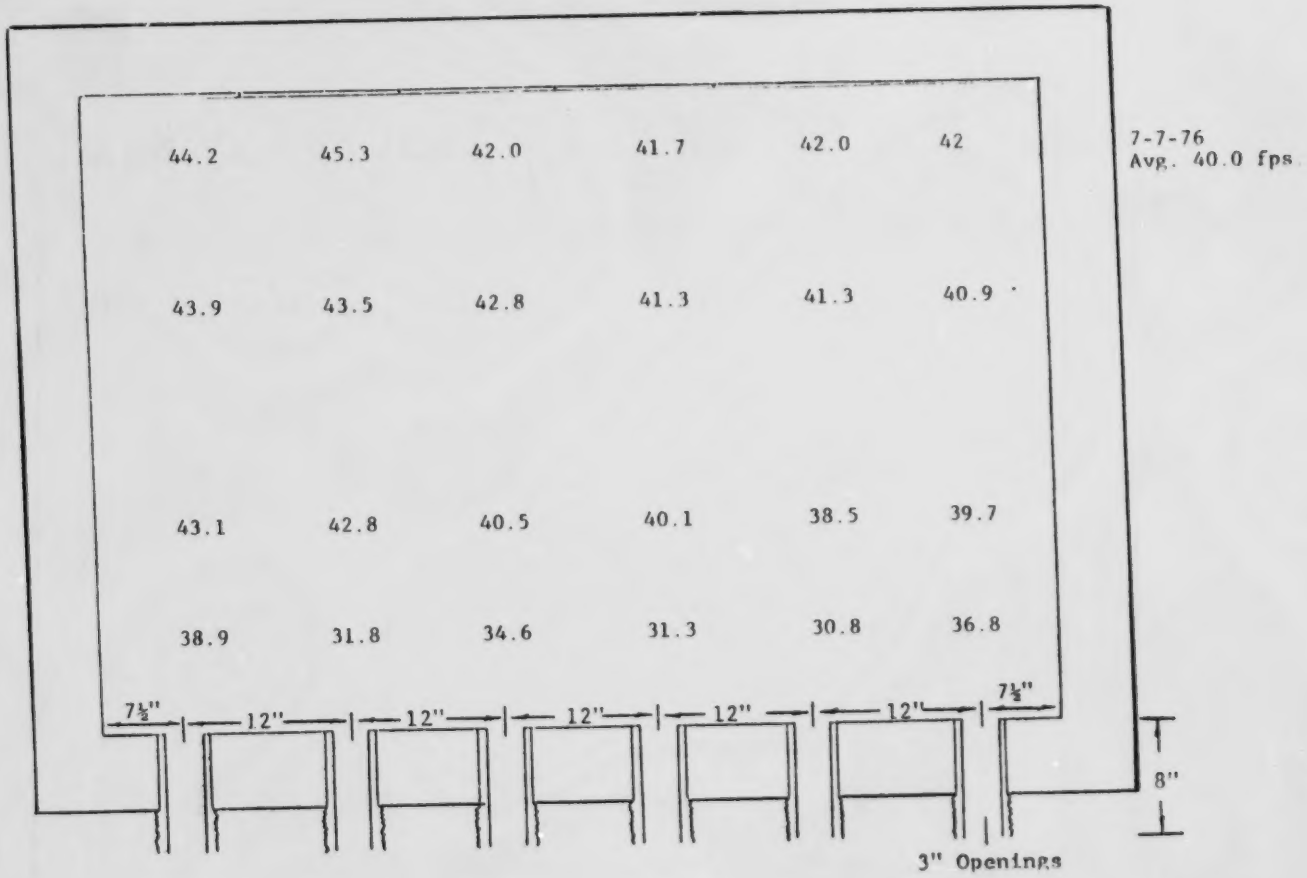


Figure 4-4. Velocity Profile of East Duct Precipitator Inlet (July 7, 1976).

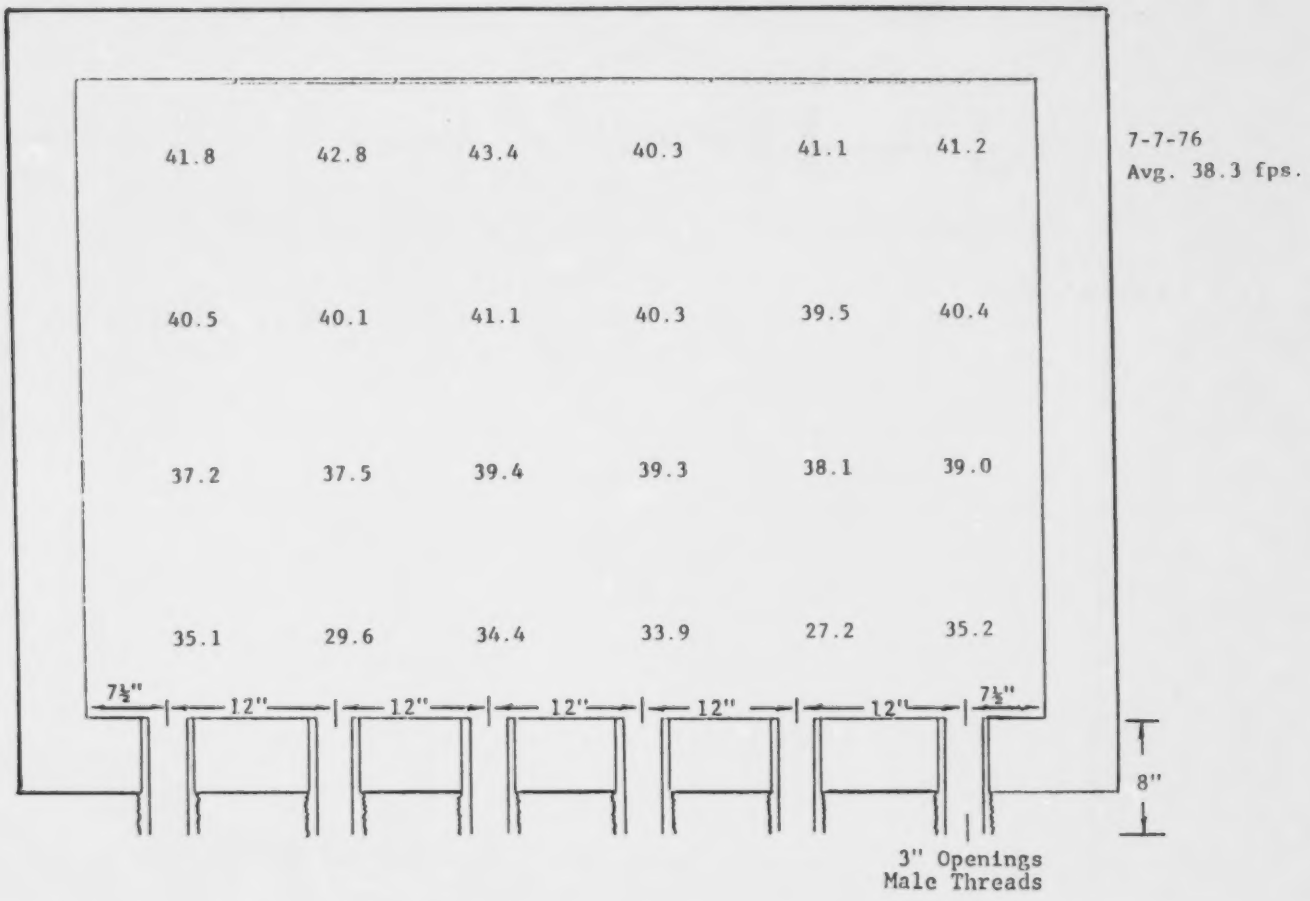


Figure 4-5. Velocity Profile of West Duct, Precipitator Inlet (July 7, 1976).

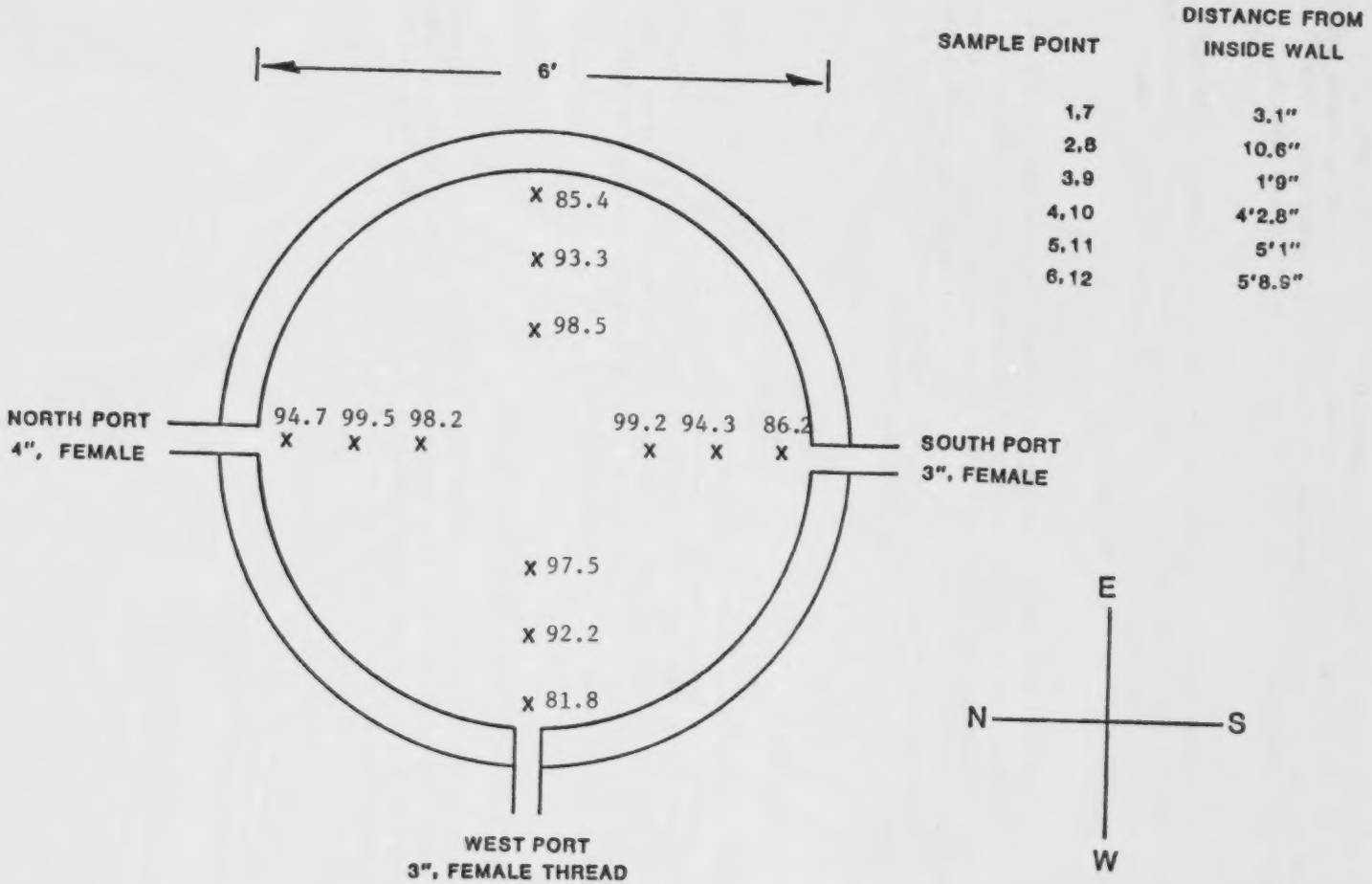


Figure 4-6. Oulet Velocity Profile (Velocities in ESP)(July 7, 1976).

As indicated above, problems were encountered due to the sticky or tacky nature of the particulates which tended to plug filtering media more quickly than would normally be expected at these grain loadings. This problem was also experienced at the ESP outlet but to a lesser extent.

Due to the method used to charge the reverberatory furnace, the ESP inlet grain loading was quite variable. The dust loading could change from light to very heavy back to light all within a few minutes. This was apparently a function of furnace charging.

On July 9 and 10, two grain loading determinations per day were made at each duct to coincide with the particle size determinations performed by Southern Research Institute (SRI) personnel using Brinks cascade impactors. Each determination consisted of a minimum of one hour sampling in each duct. An 18-point traverse was used in each of the inlet ducts, three points in each of six ports. A six-point traverse was used across one diameter of the outlet duct.

Flue Gas Composition

Samples for analysis were collected at the ESP inlet and outlet using a pump and a flexible bag. Gas from the bag was analyzed for carbon dioxide, oxygen and carbon monoxide using an Orsat gas analyzer. The gas analysis and the moisture content of the gas were used to calculate a gas density. The SO_2 and SO_3 concentrations were determined using EPA Method 8. Table 4-2 summarizes the flue gas analyses.

Measurement of Precipitator Dust Resistivity

Southern Research Institute needed the resistivity of the precipitator dust for their ESP evaluation. The samples used for these measurements were obtained during grain loading measurements. The actual resistivity determinations were made at SRI's facilities in Birmingham, Alabama.

TABLE 4-2. GAS COMPOSITION

Parameter	Method	Results	
		Inlet	Outlet
H_2O	Condensation-sorption with silica gel	13.2%	12.3%
O_2	Orsat	10.7%	9.5%
CO_2	Orsat	6.0%	6.5%
SO_2	Sorption in 6% H_2O_2-titration		
	July 15, 1977		July 15, 1977
	Run #1 0845-0855 3.43 scf	0.35%	0850-0190 3.98 scf 0.27%
	Run #2 0930-0943 4.32 scf	0.21%	0925-0945 4.22 scf 0.16%
	Run #3 1015-1028 4.40 scf	0.44%	1000-1020 4.01 scf 1.26%
	AVG.	0.33%	AVG. 0.56%
SO_3	Sorption in 80% IPA-titration		
	July 15, 1977		July 15, 1977
	Run #1 0845-0855 3.43 scf	0.005%	0850-0910 3.98 scf 0.017%
	Run #2 0930-0943 4.32 scf	0.004%	0925-0945 4.22 scf 0.006%
	Run #3 1015-1028 4.40 scf	0.009%	1000-1020 4.01 scf 0.014%
	AVG	0.006%	AVG. 0.012%

SECTION 5

ELECTROSTATIC PRECIPITATOR MATERIAL BALANCE SAMPLES

Samples of particulates and vapors from the gas stream entering and exiting the reverberatory furnace electrostatic precipitator were collected July 11 using a small wet electrostatic precipitator followed by a series of eight impingers. Dust removed by the reverberatory furnace electrostatic precipitator was sampled periodically as it was conveyed to the precipitator dust hopper. Dust hopper accumulations were monitored July 11 through 13.

PRECIPITATOR INLET AND OUTLET

The wet electrostatic precipitator (WEP) was used to capture all particulate trace elements except mercury.

Samples for characterization of the gas stream with respect to chemical composition were collected at both the precipitator inlet and outlet. These samples were collected isokinetically from points of average velocity and grain loading. Samples were drawn through a pyrex sampling nozzle and probe and then through the WEP via teflon tubing. In the WEP, shown in Figure 5-1, gas bubbles through the circulating electrolytic reservoir then passes up through a cylindrical chamber, the walls of which are wetted with the electrolyte (5% H_2SO_4). Collection of particulates and mist is achieved in this area by the 12 KVDC potential across the center plantinum electrode and the wetted outer wall which will induce electrostatic collection. The gas stream then exits at the top of the WEP. After the gas has passed through the WEP, the particulates are contained in the electrolyte.

Vapors not collected in the WEP were absorbed by a series of eight impingers. The contents of each impinger is given in Table 5-1.

Elemental mercury in the vapor phase was collected using a gold amalgamation technique. The gas is passed through 6% hydrogen peroxide to remove SO_2, then through a quartz tube containing a plug of very fine gold wire. Mercury vapor is collected on the gold surface. The mercury is later thermally desorbed and analyzed using a flameless atomic absorption technique.

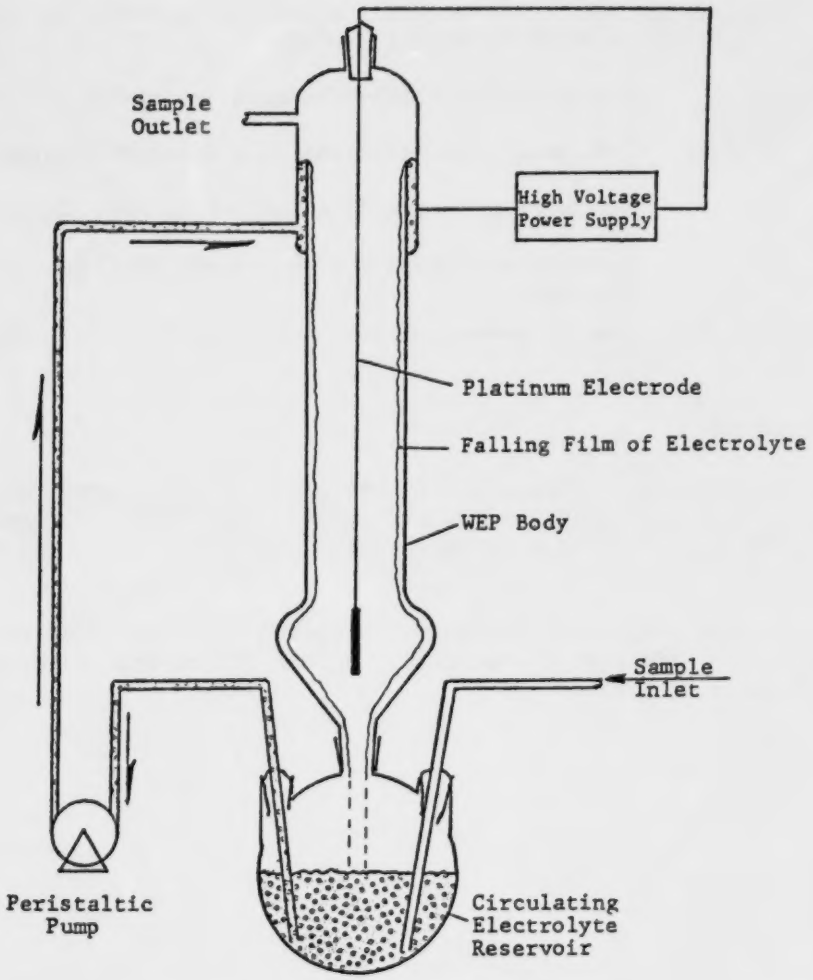


Figure 5-1. Wet Electrostatic Precipitator.

TABLE 5-1. IMPINGER SOLUTIONS USED FOR ESP MATERIAL BALANCE

Impinger Number	Solutions
1,2	1:1: sulfuric acid, nitric acid, deionized water in a Smith-Greenburg impinger
3,7	dry modified Smith-Greenburg impingers
4,5	20% potassium hydroxide in a Smith-Greenburg impinger
6	hydrogen peroxide in a Smith-Greenburg impinger
8	preweighed silica gel in a modified Smith-Greenburg impinger

PRECIPITATOR DUST

The flow rate of the precipitator catch was derived from the difference in grain loadings at the ESP inlet and outlet. The direct determination by measuring the level increase in the storage silo showed too wide variations.

An integral sample for analysis was conveniently obtained through a sampling port. This port provided easy access to the dust carried by the drag chain into the silo.

SECTION 6

REVERBERATORY FURNACE SAMPLES AND FLOWS

On July 13, hopper dust and an integral WEP at the ESP outlet sample were collected as described in Section 5. Composite matte and slag samples were obtained by plant personnel for the period July 12 through July 14. The concentrate sample was taken from the bins under the belt slinger. At the end of each shift, July 12 through 14, the concentrate from each of the slinger bins was combined in a barrel. A composite sample was finally collected for analysis.

Operating data (flow rates, temperatures, furnace level, etc.) are recorded daily. These data were made available to Radian. Table 6-1 summarizes these values. A complete material balance around the reverberatory furnace could not be completed. Samples of converter slag and converter dust were not available.

TABLE 6-1. REVERBERATORY FURNACE FLOW RATES

1. Concentrate Feed Rate:

July 11	569 tons	July 14	610 tons
July 12	600 tons	July 15	605 tons
July 13	628 tons		

2. Matte Production Rate:

July 11	504 tons	July 14	530 tons
July 12	504 tons	July 15	473 tons
July 13	504 tons		

3. Reverberatory Furnace Slag Production Rate:

July 11	420 tons	July 14	525 tons
July 12	403 tons	July 15	455 tons
July 13	420 tons		

4. Converter Slag Production Rate:

July 11	305 tons	July 14	421 tons
July 12	377 tons	July 15	377 tons
July 13	348 tons		

5. Copper Production Rate:

July 11	188 tons	July 14	180 tons
July 12	209 tons	July 15	213 tons
July 13	221 tons		

6. Converter Slag Sample for July 11-15:

No longer available

7. Anode Copper Sample for July 11-15:

No longer available.

SECTION 7

REVERBERATORY ESP FLOW RATES

Gas and particulate flow rates were determined by traversing the inlet and outlet ducts using S-type pitot tubes and in-duct Gelman filters.

Both the velocity distribution and the grain loading fluctuation were much more pronounced at the inlet than at the outlet. The gas flow rate was therefore derived from the flow measurements at the outlet. This assumes no air leakage of the ESP. Table 7-1 shows a summary of the data. The average grain loading at the ESP inlet was 0.60 grains/scf and at the outlet 0.02 grains/scf. The efficiency of the ESP is therefore 96.7%. A dust collection rate of 330 lbs/hr is calculated from these values using a total gas flow rate of 78,400 scfm.

TABLE 7-1. GAS FLOW RATE IN ACFM

Date	Inlet, East	Inlet, West	Inlet, Total	Outlet, Total
7-7-76	84000	79300	163300	160400
7-8-76	81800	79900	161700	178400
	86400	80700	167100	170800
7-9-76	81800	78500	160300	162800
	80500	67500	148000	
7-10-76	81900	78000	159900	
Stack Temp	∿625°F			
Stack Press	∿28.2" HG			

SECTION 8

SAMPLE ANALYSIS

The elements of interest in the present study are:

Arsenic	Copper	Lead
Barium	Fluorine	Sulfur
Beryllium	Mercury	Antimony
Cadmium	Molybdenum	Selenium
Chromium	Nickel	Vanadium
		Zinc

Sample analysis consists of two major steps:

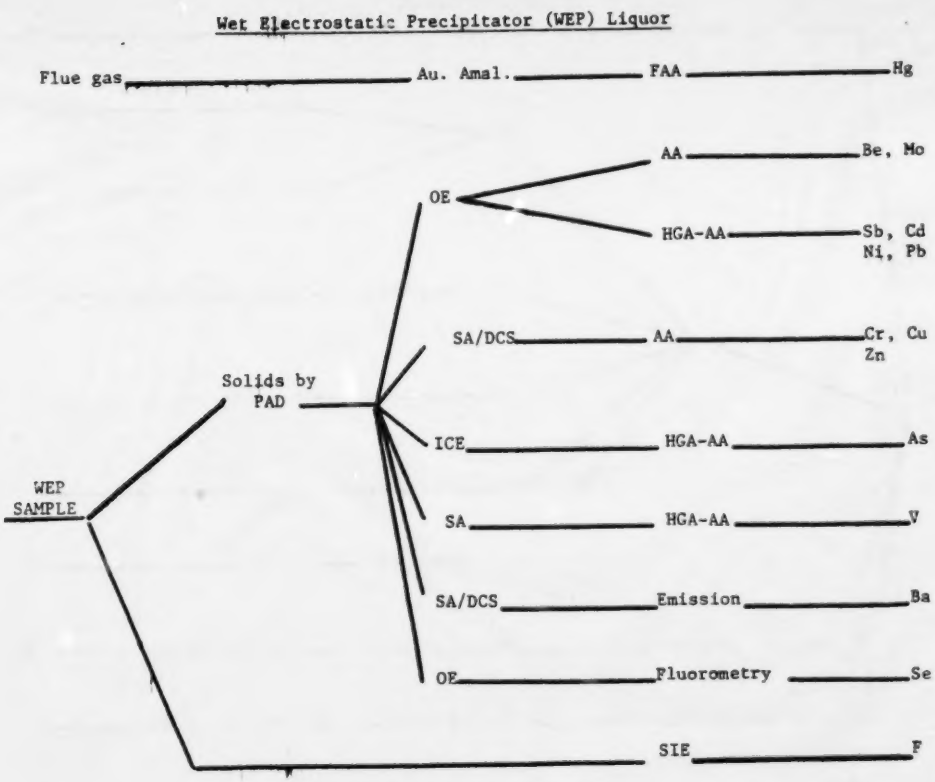
- sample dissolution and
- chemical analysis.

Sample dissolution techniques included acid reflux digestion, perchloric acid digestion and lithium borate fusion.

The techniques used for the quantitative determinations of trace elements in samples collected from the copper smelter were based on:

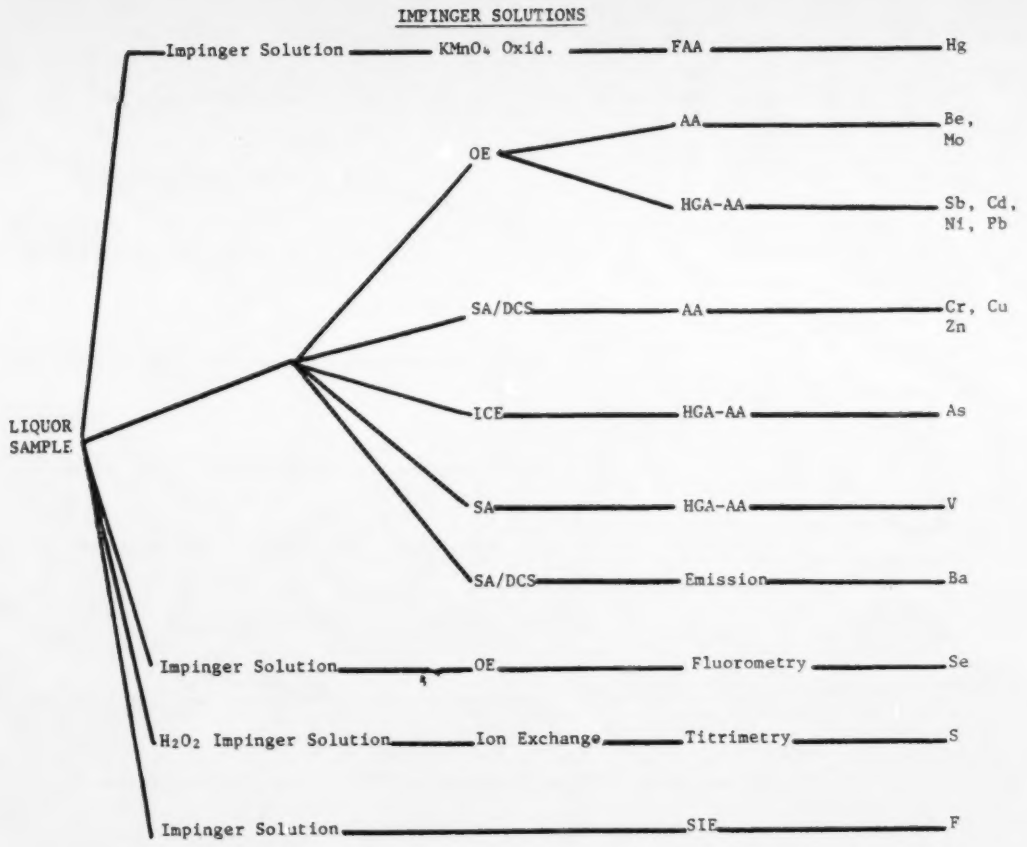
- atomic absorption,
- ion selective electrode, and
- fluorometry.

Figures 8-1 through 8-3 summarize the dissolution and analytical procedures used for the trace element determinations. The various dissolution and analytical procedures are described in the remainder of this section.



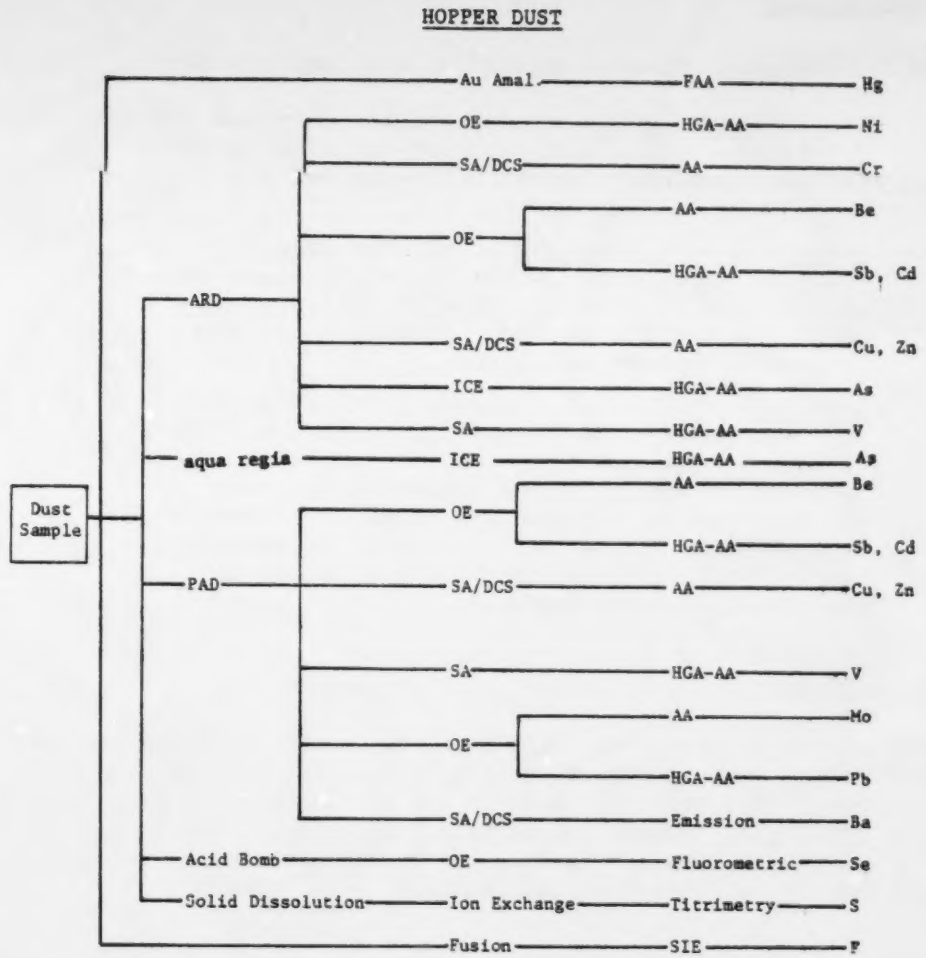
AA: atomic absorption, flame
ARD: acid reflux digestion
DCS: double capillary system
FAA: flameless atomic absorption
HGA-AA: heated graphite analyzer of the atomic absorption spectrophotometer
ICE: inorganic complex extraction
OE: organic extractior
PAD: perchloric acid digestion
SA: standard additions
SIE: specific ion electrode

Figure 8-1. Dissolution and Analytical Scheme of a WEP Slurry.



AA:	atomic absorption, flame	Acid Impinger:
ARD:	acid reflux digestion	1:1:1 HNO_3: H_2SO_4: H_2O
DCS:	double capillary system	
FAA:	flameless atomic absorption	
HGA-AA:	heated graphite analyzer of AA	Basic Impinger:
ICE:	inorganic complex extraction	20% KOH
OE:	organic extraction	
PAD:	perchloric acid digestion	
SA:	standard additions	H_2O_2 Impinger:
SIE:	specific ion electrode	5% H_2O_2

Figure 8-2. Analytical Scheme of an Impinger Liquor Sample.



AA: atomic absorption, flame
ARD: acid reflux digestion
DCS: double capillary system
HGA-AA: heated graphite analyzer of the atomic absorption spectrophotometer
HGA: heated graphite analyzer
ICE: inorganic complex extraction
OE: organic extraction
PAD: perchloric acid digestion
SA: standard additions
SIE: specific ion electrode

Figure 8-3. Dissolution and Analytical Scheme of Solid Samples.

SAMPLE PREPARATION

The dissolution techniques applied to the samples were:

- Acid Reflux Digestion - Solid samples are dissolved by refluxing with a mixture of nitric acid, sulfuric acid, and perchloric acid. Silicates are not attacked by this procedure.
- Perchloric Acid Digestion - The first step is a treatment using nitric and hydrofluoric acid. Perchloric acid is added for final oxidation of the sample. A small amount of hydrochloric is added to insure complete dissolution.
- Lithium Borate Fusion - A small amount of sample is fused with lithium borate. The cooled melt is dissolved in hydrochloric acid and hot water. Most elements present in higher concentrations were analyzed from this digestion. Elements present in trace concentrations are, in general, determined from solutions derived from the acid reflux or the perchloric acid digestion.

ANALYTICAL PROCEDURES

The analytical procedures used were originally developed for the determination of trace elements in coal, coal ashes, sludges and plant and animal tissues. The drastic change in the matrix observed in samples collected at the copper smelter necessitated screening of the procedures for accuracy and reliability. This task was accomplished using the method of standard addition and interference studies.

Mercury (KA-086, DI-043, OG-004)

Mercury is probably present in the copper ore in the form of mercury sulfide. The sulfide is roasted in the oxidizing atmosphere of the reverberatory furnace. Mercury oxide decomposes at approximately 750°F, which is well below the furnace temperature. The gold amalgamation technique was therefore chosen to collect mercury vapor in the inlet and outlet ducts of the ESP. The ultimate check of this approach was the closure of the material balance.

Gas samples are drawn through a plug of gold wool. Deamalgamation is accomplished by heating the gold wool. The released mercury is purged through the absorption cell of an atomic absorption spectrophotometer (AA).

Precipitator dust is analyzed for mercury by weighing a sample into a platinum boat and heating the sample slowly in a chamber. The off-gases containing elemental mercury are purged through a gold plug. Deamalgamation and determination by AA follow the same procedure as described above.

Liquid samples are acidified and then the mercury is oxidized with potassium permanganate. Hydroxylamine hydrochloride and stannous chloride are used to reduce the mercury to the metallic state. Air is bubbled through the solution. The mercury entrained in air is passed through the absorption cell of an AA.

Beryllium (BO-027)

Beryllium in aqueous solutions is complexed with 2,4-pentanedione. EDTA is used to mask interfering ions. The beryllium complex is extracted into methyl-isobutyl-ketone (MIBK) and aspirated into the nitrous oxide-acetylene flame of the AA.

Molybdenum (KI-092)

Molybdenum is complexed with thiocyanate, extracted into MIBK, and aspirated into the nitrous oxide-acetylene flame of the AA. Ascorbic acid and sodium fluoride mask interferences from iron and titantium. Solids are dissolved using the acid reflux digestion.

Lead and Cadmium (JO-012, KI-085)

Lead and cadmium are extracted simultaneously with MIBK from the WEP liquor, impinger solutions, and the perchloric acid digestion of the hopper dust. The double complexing agent of ammonium pyrrolidine dithiocarbamate and diethylammonium diethyldithiocarbamate chelates lead and cadmium. The extracted sample is injected into the graphite furnace attachment to the AA.

Antimony (BU-136, HE-094, ED-027)

Antimony is extracted as the iodide into a mixture of tributylphosphate and MIBK. Extraction is performed on the WEP liquor, impinger solutions and the perchloric acid digestion. Sulfamic acid is added to the acid impinger solution to remove the nitrates. Peroxide impinger solutions are boiled to decompose the H_2O_2. The extracted solution is injected into a graphite tube of the AA which has been coated with ammonium molybdate.

Nickel (JO-012)

Nickel is extracted from the WEP liquor, impinger solutions, and acid reflux digestion of the solids. Diethyldithiocarbamate is used to chelate the nickel and extract it into MIBK. The extracted sample is injected into the graphite furnace and analyzed by AA.

Chromium, Copper and Zinc (RA-155, PE-114, RU-079)

The three metals are analyzed by atomic absorption using the air-acetylene flame. The double capillary system is utilized to carry out the method of standard additions on the samples. The WEP liquor, impinger solutions and the acid reflux digestion of the solids are analyzed by this method.

Arsenic RA-147, ED-027)

The WEP liquor, impinger solutions and the perchloric acid digestion of the solids are used for the arsenic determination. Arsenic is complexed, in acidic medium, as the heteropoly acid of molybdenum. The aqueous complex is injected into the heated graphite analyzer (HGA) attachment to the atomic absorption spectrophotometer. A charring temperature of 1200^{o}C is used to remove any interferences in the HGA.

Vanadium (CI-002)

Vanadium is determined by the method of standard additions with the graphite furnace on the AA. Samples used are the WEP liquor, impinger solutions, and the acid reflux digestion of the solid. There is no sample preconcentration needed for the determination.

Barium (DE-218, RU-079)

Samples from the WEP liquor, impinger solutions, and the perchloric acid digestion are coprecipitated with lead as the dichromate and separated from the solution. The precipitate is dissolved and aspirated into the nitrous oxide-acetylene flame of the AA. The method of standard additions is utilized with the double capillary system. Most interfering species are removed by the coprecipitation procedure.

Selenium (LE-068)

Solid samples are digested in a Teflon bomb with nitric acid and perchloric acid. Following the bomb digestion, the sample is heated with dilute hydrochloric acid. WEP liquors and impinger solutions are also heated with HCl. Extraction procedures for all samples are the same from this

point forward. Following stabilization with formic acid, hydroxylamine, and EDTA, the samples are complexed with 2,3-diaminonaphthalene. The selenium complex is extracted into cyclohexane and read on a fluorometer.

Fluorine (BA-131, BA-137)

Solid samples are fused with sodium carbonate and the melt dissolved in deionized water. WEP liquors and impinger solutions are run direct. Final determination is done with a fluoride specific ion electrode utilizing the method of known additions to remove the effects of any interfering ions.

Sulfur (DO-006)

Solid samples are dissolved in a solution of hydrochloric acid and hydrogen peroxide. Solutions from the solid dissolution and the H_2O_2 impingers are boiled to remove excess peroxide. The solutions are then eluted through a cation exchange resin to convert the sulfate to sulfuric acid. Volatile acids are removed by heating and the sulfuric acid is titrated with a standard base.

The analytical accuracies of these techniques are summarized in Section 9. These values are derived by comparing analytical results with standard reference materials where available, recovery studies, and/or precision values. The estimated 95% confidence intervals are the result of these analytical studies.

SECTION 9

DATA EVALUATION

Flow rates and chemical analyses are used to calculate the transport rates of the elements of interest to the electrostatic precipitator and their discharge in the two effluent streams. Closure of the material balance enhances the validity of the individual measurements. Experimental errors are inherent in both the flow rate and analytical measurements. An error propagation analysis was applied to bracket the uncertainties in the final results. Those material balance results for which the inlet value and the sum of the two outlet streams overlap within these limits are considered too close.

MATERIAL BALANCES

The following expression is obtained by equating the total elemental flows entering and exiting the ESP:

$$F_i X_i(j) = F_o X_o(j) + M_o XW_o(j) \qquad (9\text{-}1)$$

where,

F_i = the volumetric flow rate of furnace off-gas entering the ESP (scfh),

F_o = the volumetric flow rate of furnace off-gas exiting the ESP (scfh),

M_o = the mass flow rate of precipitator dust from the ESP, (lb/h)

$X_i(j)$ = concentration of element j in the inlet flue gas, (lb/scf),

$X_o(j)$ = concentration of element j in the outlet flue gas (lb/scf),

$XW_o(j)$ = the weight fraction of the element j in the collected ESP dust.

Closure of the balance verifies the sampling and analytical techniques employed in this study.

ERROR PROPAGATION

An error propagation analysis was used to establish error limits for the calculated total inlet and outlet flow rates for each element. The values indicate the degree of variance to be expected due to random errors.

A 95% confidence interval of 2S(Q) is calculated for a given value Q according to the following defined expression:

$$S^2(Q) = \sum_{i}^{n} \left(\frac{\delta Q}{\delta q_i} \right)^2 S^2(q_i) \qquad (9\text{-}2)$$

where,

$S^2(Q)$ = the variance in Q,

Q = the mass flow rate of a given element into or out of the ESP,

q_i = the $i^{\underline{th}}$ independent measured value (stream flow rate or elemental concentration), and

$S^2(q_i)$ = the variance in q_i.

The error limits for the flow rates and analytical results used in Equation 9-2 are summarized in Tables 9-1, 9-2, and 9-3.

TABLE 9-1. FLOW RATES FOR STREAMS OF THE REVERBERATORY FURNACE ESP

Stream	Flow Rate	Error Limit	Method Used For Flow Determinations
Furnace Off-Gas	4.7×10^6 scfh	±20%	Measured with velocity traverses of the outlet duct.
Inlet Dust (in-stack measurement)	340 lbs/hr	±21%	Based on the inlet gas flow rate and inlet grain loading.
Outlet Dust (in-stack measurement)	13 lbs/hr	±21%	Based on the outlet gas flow rate and outlet grain loading.
Precipitator Dust	330 lbs/hr	±22%	Determined from the difference in the inlet and outlet dust flow rates.

TABLE 9-2. AVERAGED REVERBERATORY FURNACE FLOW RATES

Stream	Flow Rate	Estimated Error Limits	Data Source
Concentrate Feed	5.0×10^4 lbs/hr	±2.4% *	1
Matte	4.2×10^4 lbs/hr	±2.4% *	1
Reverb Slag	3.7×10^4 lbs/hr	±8.2% *	1
Converter Slag	3.0×10^4 lbs/hr	±8.6% *	1
Copper	1.7×10^4 lbs/hr	±7.2% *	1
Furnace Off-Gas	4.7×10^6 scfh	±20% **	2
Precipitator Dust	330 lbs/hr	±22% **	2

NOTE:

1 - Letter from plant personnel 2/1/77, five day average

2 - Radian estimate

* - Calculated from fluctuations

** - Radian estimate

TABLE 9-3. ESTIMATED ERROR LIMITS OF CHEMICAL ANALYSES

Element	WEP Liquor and Impingers	Dust
As	±15%	±10%
Ba	±20%	± 5%
Be	±10%	±10%
Cd	±12%	±10%
Cr	±10%	±15%
Cu	±10%	±10%
F	± 8%	±20%
Hg	±20%	±15%
Mo	±12%	±15%
Ni	±15%	±15%
Pb	±20%	± 5%
S	±10%	± 5%
Sb	±10%	±15%
Se	± 8%	±20%
V	±12%	±10%
Zn	±15%	±15%

SECTION 10

ANALYTICAL RESULTS AND MATERIAL BALANCES AROUND THE REVERBERATORY FURNACE ELECTROSTATIC PRECIPITATOR

The quantitative analyses results using the dissolution procedures and analytical methods discussed in Section 8 are listed in Table 10-1. Approximately 87 scf* of flue gas were collected at the inlet WEP train (sampling time July 11, 1976, 8:40 am - 11:40 am) and about 95 scf at the outlet WEP train (sampling time July 11, 1976, 8:42 am - 11:42 am). The weights of the WEP sample solution as well as those of the acid and alkaline impinger solutions were determined. The analytical results in Table 10-1 have the dimensions µg of element j per gram of WEP (impinger) solution and µg of element j per gram of ESP dust.

Table 10-2 relates the analytical findings to the element content in 10^6 scf of flue gas. This unit was selected for convenience regarding the numerical values. From these data and the flow rates of ESP dust, incoming and outgoing gas, the elemental flow rates in the three streams can be calculated. The results are shown in Table 10-3. Again, the contributions from the wet electrostatic precipitator and the acid and basic impingers are listed separately. The final columns show the total flows to and from the ESP. The error limits were calculated from the estimated errors in the flow rate determinations and the errors inherent in the analytical method using error propagation calculations as shown in Section 9. The balances are considered to close when the mass flow rates of a given element in and out of the ESP agree within the calculated error limits.

The survey analysis of the outlet WEP sample by spark source mass spectrometry is shown in Table 10-4. The analysis of ESP dust by the same method is shown in Table 10-5. This technique is not a suitable method for certain elements. The elements in question are marked with the symbol "ND". If no numerical value for the concentration of an element is given the concentration was found to be below the detection limit of the SSMS technique, which is about 0.1-1 ppm for solids and 1-10 ppb for liquids. Elements present as major components (>1000 ppm) are marked "MC".

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* scf is the gas volume at 760 mm Hg and 60°F on a dry basis.

TABLE 10-1. ANALYTICAL RESULTS FROM INLET AND OUTLET SAMPLING TRAINS AND PRECIPITATOR DUST (JULY 11, 1976)

Element	INLET SAMPLES					OUTLET SAMPLES					
	WEP liquor	1st acid impinger	2nd acid impinger	1st basic impinger	2nd basic impinger	WEP liquor	1st acid impinger	2nd acid impinger	1st basic impinger	2nd basic impinger	Precip-itator dust
Sample No.	790	792	793	794	795	797	799	800	801	802	806
Sample Wt.	698.0g	631.5g	631.1g	559.9g	568.8g	1120g	594.8g	567.8g	442.7g	510.1g	---
As	2250	.47	.079	<.02	2.6	1100	.13	.031	<.02	.10	9.0%
Ba	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	70
Be	.15	.001	<.001	<.001	<.001	.087	<.001	<.001	<.001	<.001	1.2
Cd	3.4	.009	<.0001	<.0001	<.0001	.13	<.0001	.0013	<.0001	<.0001	2200
Cr	.33	<.01	<.01	<.01	<.01	.092	<.01	<.01	<.01	<.01	55
Cu	680	.072	.10	.13	.27	8.3	.086	<.01	.16	.14	18.7%
F	89	3.0	.38	.32	.17	62	4.6	.20	.40	.30	98
Hg	.013	.034	.078	.010	<.001	.0071	.021	.044	.015	<.001	.46
Mo	110	.008	<.001	<.001	<.001	1.4	.028	<.001	<.001	<.001	2.0%
Ni	1.1	<.01	<.01	<.01	<.01	.70	<.01	<.01	<.01	<.01	180
Pb	11	.03	.01	<.001	<.001	.62	.05	<.001	<.001	<.001	1.6%
S	--	--	--	--	--	--	--	--	--	--	9.0%
Sb	9.8	.0013	.0020	<.0002	<.0002	2.7	<.0002	<.0002	<.0002	<.0002	3900
Se	11	<.1ppb	<.1pp	1.3ppb	12ppb	8.0	<.1ppb	<.1ppb	1.5ppb	1.0ppb	480
V	.49	.48	.14	.06	.12	.38	<.1	<.1	.45	.64	32
Zn	52	.09	.09	.05	<.01	.59	.10	.05	<.01	<.01	1.39%

All values expressed in µg element/g of sample unless noted otherwise

TABLE 10-2. ELEMENTAL CONTENT OF INCOMING AND OUTGOING ESP-STREAMS (July 11, 1976)

Element	Inlet Integral WEP[1]	Outlet Integral WEP[1]	Precipitator Dust[2]
As	39	28	9.0%
Ba	<.0018	<.0026	70
Be	0.0025	0.0022	1.2
Cd	0.061	0.0035	2200
Cr	0.0057	0.0024	55
Cu	12	.22	18.7
F	1.6	1.7	98
Hg	0.0022	0.0012	0.46
Mo	1.8	0.035	2.0%
Ni	0.020	0.018	180
Pb	0.19	0.016	1.6%
S	290[3]	500[3]	9.0%
Sb	0.19	0.069	3900
Se	0.19	0.21	480
V	0.021	0.013	32
Zn	0.91	0.017	1.4%

[1]Integral WEP values represent the total catch of the WEP plus the train of four sample collecting impingers and expressed in lbs/10^6 scf.

[2]Expressed in µg element per g of dust.

[3]Sulfur values based on SO_2-SO_3 concentration in flue gas and the sulfur content of the flue dust which were determined independently of the WEP samples.

TABLE 10-3. ELEMENTAL FLOW RATES IN ESP INLET AND OUTLET STREAMS (JULY 11, 1976)

Element	INLET (lb/hr)					Σ in (lb/hr)	OUTLET (lb/hr)						Σ out (lb/hr)
	inlet WEP liquor	1st acid impinger	2nd acid impinger	1st basic impinger	2nd basic impinger		outlet WEP liquor	1st acid impinger	2nd acid impinger	1st basic impinger	2nd basic impinger	precipitator dust	
Arsenic	190	.036	.0060	ND	1.8	190 ± 95	140	.0084	.0016	-	.0055	30	170 ± 84
Barium	ND	ND	ND	ND	ND	<.0085 ± .005	ND	ND	ND	ND	ND	.023	<.035 ± .016
Beryllium	.013	1.2×10^{-7}	ND	ND	ND	.013 ± .006	.011	ND	ND	ND	ND	.00040	.011 ± .005
Cadmium	.29	.00068	ND	ND	ND	.29 ± .13	.016	ND	8.1×10^{-5}	ND	ND	.74	.74 ± .34
Chromium	.027	ND	ND	ND	ND	.027 ± .012	.011	ND	ND	ND	ND	.018	.029 ± .007
Copper	56	.0054	.0075	.0086	.018	56 ± 25	1.0	.0055	ND	.0077	.0077	62	63 ± 28
Fluorine	7.4	.23	.029	.021	.0012	7.6 ± 3.2	7.5	.29	.012	.020	.016	.032	7.8 ± 3.4
Mercury	.0011	.0025	.0059	.00066	ND	.010 ± .006	.00087	.0013	.0027	.00072	ND	.00015	.006 ± .003
Molybdenum	8.7	.00060	ND	ND	ND	8.7 ± 4.0	.16	.0018	ND	ND	ND	6.6	6.8 ± 3.4
Nickel	.092	ND	ND	ND	ND	.09 ± .05	.085	ND	ND	ND	ND	.059	.14 ± .07
Lead	.92	.0023	.00072	ND	ND	.92 ± .52	.075	.0035	ND	ND	ND	5.3	5.4 ± 2.2
Sulfur	(1320 lb/hr S as SO_2, 30 lb/hr S as SO_3, 30 lb/hr in flue dust)					1400 ± 640	(2210 lb/hr S as SO_2, 50 lb/hr S as SO_3, 1.2 lb/hr in flue dust)					30	2290 ± 1040
Antimony	.81	9.8×10^{-5}	.00025	ND	ND	.81 ± .36	.33	ND	ND	ND	ND	1.3	1.6 ± .80
Selenium	.91	ND	ND	8.6×10^{-5}	.00078	.91 ± .34	.97	ND	ND	7.2×10^{-5}	5.5×10^{-5}	.16	1.1 ± .5
Vanadium	.041	.036	.011	.0039	.0081	.099 ± .046	.0047	ND	ND	.022	.035	.011	.073 ± .032
Zinc	4.3	.0068	.0068	.0033	ND	4.3 ± 2.2	.072	.0064	.0032	ND	ND	4.6	4.7 ± 2.3

TABLE 10-4. SURVEY ANALYSIS OF THE OUTLET WEP SAMPLE BY SPARK SOURCE MASS SPECTROMETRY (JULY 11, 1976)

CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.004
Thorium		Gadolinium		Molybdenum	2	Titanium	0.2
Bismuth	0.02	Europium		Niobium		Scandium	<0.001
Lead	0.1	Samarium		Zirconium		Calcium	MC
Thallium		Neodymium		Yttrium		Potassium	9
Mercury	NR	Praseodymium		Strontium	0.03	Chlorine	0.4
Gold		Cerium	0.01	Rubidium	0.002	Sulfur	4
Platinum		Lanthanum	0.02	Bromine		Phosphorus	0.5
Iridium		Barium	0.2	Selenium	2	Silicon	1
Osmium		Cesium	≤0.003	Arsenic	MC	Aluminum	0.7
Rhenium		Iodine		Germanium	0.01	Magnesium	0.8
Tungsten		Tellurium		Gallium	≤0.005	Sodium	4
Tantalum		Antimony	0.04	Zinc	0.4	Fluorine	≈0.06
Hafnium		Tin		Copper	9	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.04	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	0.002	Carbon	NR
Thulium		Silver	0.02	Iron	0.8	Boron	0.02
Erbium		Palladium		Manganese	0.009	Beryllium	
Holmium		Rhodium		Chromium	0.05	Lithium	0.008
Dysprosium						Hydrogen	NR

NR - SSMS technique is not suitable.
No value listed: Element concentration is below the detection limit of SSMS (0.1-1 ppm for solids, 1-10 ppb for liquids)
MC - Major component.

TABLE 10-5. SURVEY ANALYSIS OF THE PRECIPITATOR DUST BY SPARK SOURCE MASS SPECTROMETRY (JULY 11-13, 1976)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	≤2	Terbium	0.3	Ruthenium		Vanadium	6
Thorium	≤3	Gadolinium	0.8	Molybdenum	MC	Titanium	MC
Bismuth	650	Europium	0.5	Niobium	1	Scandium	2
Lead	MC	Samarium	2	Zirconium	10	Calcium	MC
Thallium	15	Neodymium	1	Yttrium	2	Potassium	MC
Mercury	NR	Praseodymium	0.8	Strontium	22	Chlorine	38
Gold		Cerium	8	Rubidium	39	Sulfur	MC
Platinum		Lanthanum	4	Bromine	7	Phosphorus	MC
Iridium		Barium	36	Selenium	410	Silicon	MC
Osmium		Cesium	5	Arsenic	MC	Aluminum	>340
Rhenium		Iodine	2	Germanium	31	Magnesium	MC
Tungsten	≤2	Tellurium	110	Gallium	5	Sodium	MC
Tantalum		Antimony	MC	Zinc	MC	Fluorine	≈95
Hafnium		Tin	250	Copper	MC	Oxygen	NR
Lutetium		Indium	STD	Nickel	100	Nitrogen	NR
Ytterbium		Cadmium	330	Cobalt	21	Carbon	NR
Thulium		Silver	140	Iron	MC	Boron	8
Erbium		Palladium		Manganese	38	Beryllium	0.5
Holmium		Rhodium		Chromium	31	Lithium	12
Dysprosium						Hydrogen	NR

NR - SSMS technique is not suitable.
No value listed: Element concentration is below the detection limit of SSMS (0.1-1 ppm for solids, 1-10 ppb for liquids)
MC - Major component.

SECTION 11

REVERBERATORY FURNACE MATERIAL BALANCE

The quantitative analysis results for the samples collected around the reverberatory furnace are given in Table 11-1. Approximately 131 cubic feet (at 60°F and 29.92" Hg on a dry basis) of furnace off-gas were collected at the electrostatic precipitator outlet on July 13, 1976 between 06:35 and 10:28 am. At the completion of sampling the weights of the analytical solutions, the WEP liquor and five impinger solutions were recorded. The analytical results for each solution reported in Table 11-1 have units of μg of element j per gram of analytical solution unless noted otherwise.

The electrostatic precipitator dust was collected by Radian personnel during the period July 11-13, 1976. The other solid samples, matte, slag, and feed were composites of six shift samples supplied by plant personnel. Analytical values for these samples are also expressed in μg/gram unless otherwise noted.

Table 11-2 gives the elemental flow rates for each stream. The summation of the elemental flow rates of all incoming and outgoing streams are also given. It should be noted that samples of the converter slag, the converter dust, and the reverberatory furnace waste heat boiler dust were not available.

Survey analysis of the reverb feed, matte, and reverb slag by SSMS are given in Tables 11-3, 11-4 and 11-5.

TABLE 11-1. ANALYTICAL RESULTS FROM STREAMS AROUND THE REVERBERATORY FURNACE (JULY 11-14, 1976)

	INCOMING STREAMS			OUTGOING STREAMS								
	Reverb Feed	Converter Slag	Converter Dust	Matte	Slag	Waste Heat Boiler Dust	WEP Liquor	1st acid Impinger	2nd acid Impinger	1st basic Impinger	2nd basic Impinger	Peroxide Impinger	Precipitator Dust
Al	8000	SAMPLE NOT AVAILABLE	SAMPLE NOT AVAILABLE	<400	1.9%	SAMPLE NOT AVAILABLE	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.1
As	0.39%			1100	1300		750	<.1	<.1	.15	.071	.28	9.0%
Ba	620			790	1200		2.6	1.6	1.7	1.2	1.4	2.1	70
Be	1.4			0.10	0.85		<.01	<.01	<.01	<.01	<.01	<.01	1.2
Ca	1.5%			290	5.2%		.13	<.01	<.01	.08	.061	.080	6400
Cd	1200			880	9.0		.71	.007	.005	.005	<.001	<.001	2200
Cr	15.0			15.0	100		.15	.087	.067	.31	.25	.033	55
Cu	32%			42%	5900		18	.11	.04	.29	.33	.26	19%
F	67			<.29	55		87	6.4	.75	.92	1.2	.17	98
Fe	21%			27%	32%		3.8	.91	.99	.96	.64	<.01	13%
Hg	.37			.48	.24		.28	.038	.010	.022	.02	1.9 ppb	.46
Mo	1600			200	2400		1.60	<.005	<.005	<.005	<.005	<.005	2.0%
Ni	14			49	20		.089	<.005	<.005	.034	.021	<.005	180
Pb	980			2000	350		3.8	.011	.015	.011	<.001	<.001	1.6
Sb	120			110	92		.27	<.01	.023	.010	.017	.024	3900
Se	200			4.0	150		6.4	.082	.050	3.5 ppb	.019	.011	480
Si	2.1%			<1000	13%		4.1	5.0	5.0	13	.061	4.4	.51%
V	18			7.9	23		<.01	.028	.13	.072	.28	.072	32
Zn	830			750	810		1.8	1.4	.15	.37	.11	.005	1.4%

NOTE: All values expressed in µg/g unless otherwise noted.

TABLE 11-2. ELEMENT FLOW RATES IN THE FEED AND DISCHARGE STREAMS OF THE REVERBERATORY FURNACE (JULY 11-14, 1976)

Element	Incoming Streams				Outgoing Streams					
	Reverb Feed	Converter Slag	Converter Dust	Total	Matte	Slag	Flue Outlet	ESP* Catch	Waste Heat* Boiler Dust	Total
Al	400			>400	<17	700	0.10	1.1		700
As	190			>190	48	48	76	30		200
Ba	31			>31	33	43	0.64	0.023		76.2
Be	0.072	SAMPLE NOT AVAILABLE	SAMPLE NOT AVAILABLE	>0.072	4.1×10^{-3}	0.032	3.4×10^{-3}	4.0×10^{-4}	SAMPLE NOT AVAILABLE	0.039
Ca	770			>770	12	1.9×10^{3}	0.011	2.1		2000
Cd	59			>59	37	0.33	.076	0.74		46
Cr	0.076			>0.076	0.64	3.8	0.044	0.018		4.5
Cu	1.6×10^{4}			$>1.6 \times 10^{4}$	1.8×10^{4}	2.2×10^{2}	1.8	62		1.8×10^{4}
F	3.4			>3.4	0.012	2.2	9.4	0.032		12
Fe	1.0×10^{4}			$>1.0 \times 10^{4}$	1.1×10^{4}	1.2×10^{4}	0.55	42.6		2.3×10^{4}
Hg	0.018			>0.018	0.020	9.1×10^{-3}	0.033	1.5×10^{-4}		0.062
Mo	79			>79	8.5	89	0.17	6.6		100
Ni	0.70			>0.70	2.0	0.76	0.011	0.059		29
Pb	49			>49	84	13	0.38	5.3		100
Sb	6.0			>6.0	4.6	3.4	0.030	1.3		9.4
Se	10			>10	0.17	5.5	0.65	0.16		6.5
Si	1100			>1100	<42	4.8×10^{3}	1.7	1.7		4800
V	0.92			>0.92	0.33	0.86	0.027	0.011		1.2
Zn	42			>42	31	30	0.22	4.6		66

* These streams were not recycled during the time of ESP sampling.

TABLE 11-3. SURVEY ANALYSIS OF THE REVERBERATORY FURNACE FEED BY SSMS (JULY 12-14, 1976)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	2	Terbium	0.4	Ruthenium		Vanadium	11
Thorium	4	Gadolinium	1	Molybdenum	340	Titanium	MC
Bismuth	80	Europium	0.6	Niobium	3	Scandium	3
Lead	910	Samarium	3	Zirconium	*32	Calcium	MC
Thallium	≤1	Neodymium	6	Yttrium	5	Potassium	MC
Mercury	NR	Praseodymium	3	Strontium	36	Chlorine	25
Gold	0.7	Cerium	17	Rubidium	19	Sulfur	MC
Platinum		Lanthanum	10	Bromine	5	Phosphorus	15
Iridium		Barium	320	Selenium	110	Silicon	MC
Osmium		Cesium	0.7	Arsenic	MC	Aluminum	>250
Rhenium	0.5	Iodine	1	Germanium	2	Magnesium	MC
Tungsten	2	Tellurium	4	Gallium	6	Sodium	>600
Tantalum	≤0.6	Antimony	70	Zinc	330	Fluorine	*160
Hafnium		Tin	9	Copper	MC	Oxygen	NR
Lutetium		Indium	STD	Nickel	190	Nitrogen	NR
Ytterbium		Cadmium	*16	Cobalt	17	Carbon	NR
Thulium		Silver	40	Iron	MC	Boron	2
Erbium	0.4	Palladium		Manganese	25	Beryllium	<0.1
Holmium	0.7	Rhodium		Chromium	10	Lithium	1
Dysprosium	1					Hydrogen	NR

NR - SSMS technique is not suitable.
No value listed: Element concentration is below the detection limit of SSMS (0.1-1 ppm for solids, 1-10 ppb for liquids)
MC - Major component, (>1000 ppm).
* - Heterogeneous

TABLE 11-4. SURVEY ANALYSIS OF MATTE BY SPARK SOURCE MASS SPECTROMETRY (JULY 12-14, 1976)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	≤3	Terbium		Ruthenium		Vanadium	1
Thorium	≤3	Gadolinium		Molybdenum	170	Titanium	26
Bismuth	120	Europium		Niobium		Scandium	≤0.4
Lead	MC	Samarium		Zirconium	5	Calcium	MC
Thallium	3	Neodymium		Yttrium	2	Potassium	MC
Mercury	NR	Praseodymium	0.4	Strontium	14	Chlorine	19
Gold	3	Cerium	0.7	Rubidium	3	Sulfur	MC
Platinum		Lanthanum	0.9	Bromine	1	Phosphorus	6
Iridium		Barium	36	Selenium	410	Silicon	470
Osmium		Cesium	0.2	Arsenic	MC	Aluminum	>350
Rhenium		Iodine		Germanium		Magnesium	15
Tungsten		Tellurium	6	Gallium	0.2	Sodium	MC
Tantalum		Antimony	180	Zinc	MC	Fluorine	≈25
Hafnium		Tin	30	Copper	MC	Oxygen	NR
Lutetium		Indium	STD	Nickel	60	Nitrogen	NR
Ytterbium		Cadmium	50	Cobalt	570	Carbon	NR
Thulium		Silver	110	Iron	MC	Boron	0.4
Erbium		Palladium		Manganese	34	Beryllium	
Holmium		Rhodium		Chromium	15	Lithium	1
Dysprosium						Hydrogen	NR

NR - SSMS technique is not suitable.
No value listed: Element concentration is below the detection limit of SSMS (0.1-1 ppm for solids, 1-10 ppb for liquids)
MC - Major component, (>1000 ppm).
* - Heterogeneous

TABLE 11-5. SURVEY ANALYSIS OF REVERBERATORY FURNACE SLAG BY SSMS (JULY 12-14, 1976)

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	9	Terbium	0.5	Ruthenium		Vanadium	15
Thorium	24	Gadolinium	3	Molybdenum	MC	Titanium	MC
Bismuth	5	Europium	1	Niobium	10	Scandium	4
Lead	370	Samarium	10	Zirconium	130	Calcium	MC
Thallium		Neodymium	12	Yttrium	18	Potassium	MC
Mercury	NR	Praseodymium	10	Strontium	130	Chlorine	95
Gold		Cerium	65	Rubidium	44	Sulfur	MC
Platinum		Lanthanum	50	Bromine	2	Phosphorus	MC
Iridium		Barium	270	Selenium	25	Silicon	MC
Osmium		Cesium	4	Arsenic	MC	Aluminum	>250
Rhenium		Iodine		Germanium	0.6	Magnesium	MC
Tungsten	4	Tellurium		Gallium	8	Sodium	>640
Tantalum		Antimony	160	Zinc	MC	Fluorine	≈60
Hafnium	3	Tin	15	Copper	MC	Oxygen	NR
Lutetium	0.3	Indium	STD	Nickel	14	Nitrogen	NR
Ytterbium	1	Cadmium	4	Cobalt	38	Carbon	NR
Thulium	0.3	Silver	1	Iron	MC	Boron	2
Erbium	1	Palladium		Manganese	260	Beryllium	0.2
Holmium	1	Rhodium		Chromium	120	Lithium	2
Dysprosium	5					Hydrogen	NR

NR- SSMS technique is not suitable.
No value listed: Element concentration is below the detection limit of SSMS (0.1-1 ppm for solids, 1-10 ppb for liquids)
MC - Major component, (>1000 ppm).
* - Heterogeneous

SECTION 12

X-RAY FLUORESCENCE AND SSMS ANALYSES OF MATERIAL CONDENSED IN IMPINGERS

The cumulative material condensed in the impingers during in-duct, out-of-duct grain loading determination was mixed in an approximate ratio of 1:4 with boric acid and compressed into a pellet. This pellet was qualitatively analyzed for most elements heavier than iron using X-ray fluorescence in the scanning mode. A Siemens Sequential X-Ray Spectrometer was used. Scanning conditions included:

- chromium target tube, 50 Kv, 48 ma,
- LiF(100) crystal,
- scintillation counter,
- pulse height discriminator settings:
  baseline 0.56 volts
  window width 0.90 volts,
- scanning rate 2°/minute,
- chart speed 20 cm/minute, and
- scanning range 2θ = 9 to 57°.

The scanning range indicated covers K_α lines for elements cobalt (atomic No. 27) through promethium (61) and L_α lines for elements dysprosium (66) through uranium (92).

Table 12-1 lists the elements of interest in the present study. Comments indicate which elements would not have been detected by X-ray fluorescence under the conditions used. For those elements with K or L lines within the scanning range, the positions of analytical lines are listed with net peak intensities above background for the sample pellet and for a pellet of pure boric acid.

The peak intensities listed in Table 12-1 indicate that arsenic and selenium are the predominant heavy elements in this sample. The presence of a smaller amount of zinc is indicated. Small amounts of copper and lead may also be present although the observed increases in peak intensities are near experimental detectabilities. Other fluctuations in peak intensities are within experimental error.

TABLE 12-1. X-RAY FLUORESCENCE INTENSITIES FOR ELEMENTS OF INTEREST

Element Symbol	Atomic Number	Analytical line	2θ for LiF(100) crystal (degrees)	Fluorescent Intensity for H_3BO_3 (counts/sec)	Fluorescent Intensity for Condensate Sample (counts/sec)
As	33	$K_{\alpha_{1,2}}$	34.00	<100	5900
		$K_{\beta_{1,3}}$	30.45	<100	1280
Ba	56	$K_{\alpha_{1,2}}$	11.02	<120	<120
Be	4	Too light for X-ray fluorescence determination			
Cd	48	$K_{\alpha_{1,2}}$	15.31	<160	<160
Cr	24	$K_{\alpha_{1,2}}$	69.36	Not in scanning range used	
Cu	29	$K_{\alpha_{1,2}}$	45.03	1120*	1380
		$K_{\beta_{1,3}}$	40.46	260*	360
F	9	Too light for X-ray fluorescence determination			
Hg	80	L_{α_1}	35.91	<80	<80
Mo	42	$K_{\alpha_{1,2}}$	20.33	<100	<120
Ni	28	$K_{\alpha_{1,2}}$	48.67	160*	160
Pb	82	L_{α_1}	33.93	<100	(5900)**
		L_{β_1}	28.26	<120	240
S	16	Not in range of LiF(100) crystal			
Sb	51	$K_{\alpha_{1,2}}$	13.42	<200	<150
Se	34	$K_{\alpha_{1,2}}$	31.89	<80	1120
		$K_{\beta_{1,3}}$	28.54	<80	250
V	23	$K_{\alpha_{1,2}}$	76.94	Not in scanning range used	
Zn	30	$K_{\alpha_{1,2}}$	41.80	740*	1120
		$K_{\beta_{1,3}}$	37.53	160*	260

* Some net peak intensity is always observed for Ni, Cu, Zn. These intensities derive from materials of construction of the X-ray spectrometer.

** This line is not resolved from the As K_{α} line at 2θ = 34.00 degrees. The intensities of the As $K_{\beta_{1,3}}$ line and the Pb L_{β_1} line indicate that the major portion of this peak should be assigned to arsenic.

The results of a survey analysis by spark source mass spectroscopy are shown in Table 12-2. Again, arsenic and selenium are indicated to be present as major species. Species found in smaller concentrations are lead, rhenium and zinc.

TABLE 12-2. SURVEY ANALYSIS OF THE CONDENSIBLES BY SPARK SOURCE MASS SPECTROMETRY

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	2
Thorium		Gadolinium		Molybdenum	25	Titanium	100
Bismuth		Europium		Niobium		Scandium	≤0.9
Lead	15	Samarium		Zirconium	10	Calcium	MC
Thallium		Neodymium		Yttrium	3	Potassium	420
Mercury	NR	Praseodymium		Strontium	5	Chlorine	130
Gold		Cerium	4	Rubidium	0.7	Sulfur	700
Platinum		Lanthanum	8	Bromine	10	Phosphorus	260
Iridium		Barium	16	Selenium	MC	Silicon	MC
Osmium		Cesium		Arsenic	MC	Aluminum	340
Rhenium	370	Iodine	40	Germanium		Magnesium	MC
Tungsten		Tellurium		Gallium	3	Sodium	870
Tantalum		Antimony	7	Zinc	100	Fluorine	≈50
Hafnium		Tin	7	Copper	MC	Oxygen	NR
Lutetium		Indium	STD	Nickel	36	Nitrogen	NR
Ytterbium		Cadmium	≤6	Cobalt	1	Carbon	NR
Thulium		Silver	6	Iron	770	Boron	2
Erbium		Palladium		Manganese	6	Beryllium	
Holmium		Rhodium		Chromium	97	Lithium	1
Dysprosium						Hydrogen	NR

NR - SSMS technique is not suitable.
No value listed: Element concentration is below the detection limit of SSMS (0.1-1 ppm for solids, 1-10 ppb for liquids)
MC - Major component, (>1000 ppm).
* - Heterogeneous

SECTION 13

IDENTIFICATION OF MAJOR CRYSTALLINE SPECIES

In an effort to determine the major chemical compounds present in the emissions from the reverberatory furnace, six samples were studied using X-ray diffraction:

- reverberatory furnace feed concentrate (collected July 13, 1976, 11:10 pm "C" shift),
- dust collected by the electrostatic precipitator (taken from screw conveyor, July 11, 1976),
- particulate, collected at the ESP outlet using an in-stack filter (July 10, 1976, from 6:30 to 8:14 am),
- condensed particulate - collected at the ESP outlet at 250°F preceded by an in-stack filter at 600°F (July 15, 1976, from 8:50 to 10:20 am),
- condensed particulate - collected at the ESP inlet at 250°F preceded by an in-stack filter at 600°F; this filter was unusual in that the collected material was black while that on all other filters used in this manner was very light in color (July 15, 1977, 1:00 pm to 2:20 pm), and
- material which condensed in the glassware following the filter oven during modified EPA Method 5 sampling (composite sample).

Copper K_α radiation was used in the X-ray studies.

Most of the pattern obtained for the reverberatory furnace feed concentrate is reproduced in Figure 13-1. Table 13-1 lists most of the recognizable peaks and the crystalline species which have been assigned to account for them. Two crystalline phases have been identified in the reverberatory furnace feed concentrate: Chalcopyrite ($CuFeS_2$) and α-Quartz (SiO_2). These two species dominate the pattern. Several small peaks remain unassigned and may represent a complex mixture of minor crystalline components.

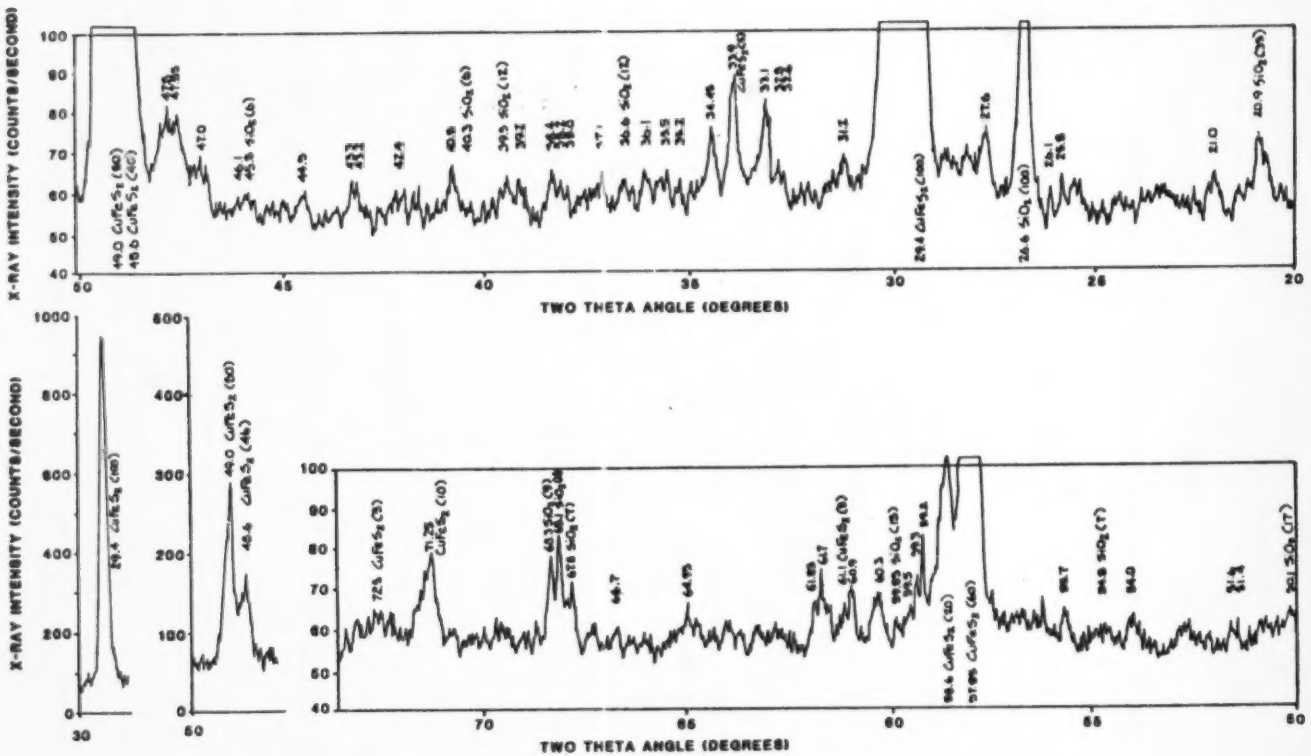


Figure 13-1. X-Ray Powder Diffraction Pattern - Reverberatory Furnace Feed Concentrate (Collected July 13, 1976, 11:10 pm "C" Shift).

TABLE 13-1. X-RAY POWDER DIFFRACTION PATTERN - REVERBERATORY FURNACE FEED CONCENTRATE (COLLECTED JULY 13, 1976, 11:10 PM "C" SHIFT)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES							
			α-Quartz SiO_2		Chalcopyrite $CuFeS_2$					
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 6$	d Angstroms	$I/I_o \geq 5$	d Angstroms	$I/I_o \geq$	d Angstroms	$I/I_o \geq$
7.5	11	11.7								
8.6	16	10.2								
9.4	12	9.36								
11.4	13	7.73								
11.6	14	7.60								
17.5	12	5.05								
17.8	10	4.97								
18.2	10	4.86								
18.85	10	4.71								
20.9	21	4.24	4.26	35						
21.0	12	4.22								
25.8	13	3.447								
26.1	10	3.408								
26.6	145	3.345	3.343	100						
27.6	26	3.226								
29.4	900	3.033			3.03	100				
31.2	17	2.862								
32.6	9	2.743								
32.8	17	2.726								
33.1	32	2.702								
33.9	38	2.640			2.63	5				
34.45	25	2.603								
35.2	11	2.546								
35.5	14	2.525								
36.1	14	2.485								
36.6	11	2.452	2.458	12						
37.1	13	2.420								
38.0	9	2.365								
38.2	10	2.353								
38.4	13	2.341								

(Continued)

TABLE 13-1. X-RAY POWDER DIFFRACTION PATTERN - REVERBERATORY FURNACE FEED CONCENTRATE (COLLECTED JULY 13, 1976, 11:10 PM "C" SHIFT)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES							
			α-Quartz SiO_2		Chalcopyrite $CuFeS_2$					
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 6$	d Angstroms	$I/I_o \geq 5$	d Angstroms	$I/I_o \geq$	d Angstroms	$I/I_o \geq$
39.2	11	2.295								
39.5	12	2.279	2.282	12						
40.3	6	2.235	2.237	6						
40.8	15	2.209								
42.4	5	2.129	2.128	9						
43.2	12	2.092								
43.3	12	2.087								
44.5	8	2.034								
45.8	8	1.979	1.980	6						
46.1	8	1.967								
47.0	16	1.931								
47.55	28	1.912								
47.8	26	1.901								
48.6	120	1.872			1.865	40				
49.0	240	1.857			1.854	80				
50.1	12	1.819	1.817	17						
51.4	8	1.776								
51.6	4	1.770								
54.0	10	1.697								
54.8	6	1.674	1.672	7						
55.7	11	1.649								
[56.3	60 (15)	1.633]								
[56.4	35 (11)	1.630]								
57.85	115	1.594			1.591	60				
58.6	70	1.574			1.573	20				
59.2	45	1.560								
59.3	20	1.557								
59.5	12	1.552								
59.85	9	1.545	1.541	15						
60.3	15 (B)	1.534								

(Continued)

TABLE 13-1. X-RAY POWDER DIFFRACTION PATTERN - REVERBERATORY FURNACE FEED CONCENTRATE (COLLECTED JULY 13, 1976, 11:10 PM "C" SHIFT)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES							
			α-Quartz SiO_2		Chalcopyrite $CuFeS_2$					
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 6$	d Angstroms	$I/I_o \geq 5$	d Angstroms	$I/I_o \geq$	d Angstroms	$I/I_o \geq$
60.9	18	1.520			1.518	5				
61.1	12	1.516								
61.7	21	1.502								
61.85	13	1.500								
64.95	13	1.436								
66.7	7	1.401								
67.8	17	1.381	1.382	7						
68.1	30	1.376	1.375	11						
68.3	25	1.372	1.372	9						
71.25	26	1.3234			1.323	10				
72.5	12	1.302			1.303	5				
75.3	12	1.2613								
78.9	22	1.2126			1.214	10				
79.5	28	1.2050			1.205	30				
79.8	22	1.2012								

The source for the standards was the X-Ray Powder Diffraction Data File. The pattern for silica is listed on Card Number 5-490 and that for Chalcopyrite on Card Number 9-423.

The powder diffraction patterns of the five solids obtained from effluent gases all contained Arsenolite (As_2O_3). Significant portions of the patterns are presented in Figures 13-2 through 13-6. Peak idenfifications and assignments are listed in Tables 13-2 through 13-6.

In complex patterns such as those obtained for material from the dust hopper and material collected on the in-stack filter, it is often not possible to identify more than three or four species with a high degree of confidence. The degree of confidence in peak assignments generally decreases as one goes to the right in the tables. The first three species listed for the dust hopper, α-Quartz, Arsenolite and Chalcocyanite can, quite assuredly, be said to be present. The presence of the remaining species is not so certain. However, the peak assignments are reasonable and consistent with what is presently known of the elemental composition of the sample. For the material collected on the in-stack filter, hydrates of copper sulfate share predominance with the arsenolite. The material collected on the in-stack filter was a bright blue color. Unidentified peaks remain on both these patterns.

Material collected on the out-of-stack filters had passed through the in-stack filter at 315°C (600°F), presumably in the gas phase, and was collected at 120°C (250°F). The crystalline portion of this material is almost pure As_2O_3. Very little difference was observed between the X-ray patterns for material which was almost white and that which was black.

As filtered gas was passed through the sampling train, some material condensed on the surfaces of the lines leading to the first impinger. This material was initially highly colored and oily in appearance. As time passed, this material lost much of its color and seemed to become more crystalline. Two major peaks appear on the pattern for this aged material in addition to the patterns for Arsenolite. These peaks have not yet been assigned.

Table 3-17 summarizes the crystalline materials identified in the six samples discussed above. The persistent presence of Arsenolite (As_2O_3) in materials leaving the reverberatory furnace is striking. The blue color of the material collected on the in-stack filter can be attributed to the presence of copper sulfate pentahydrate.

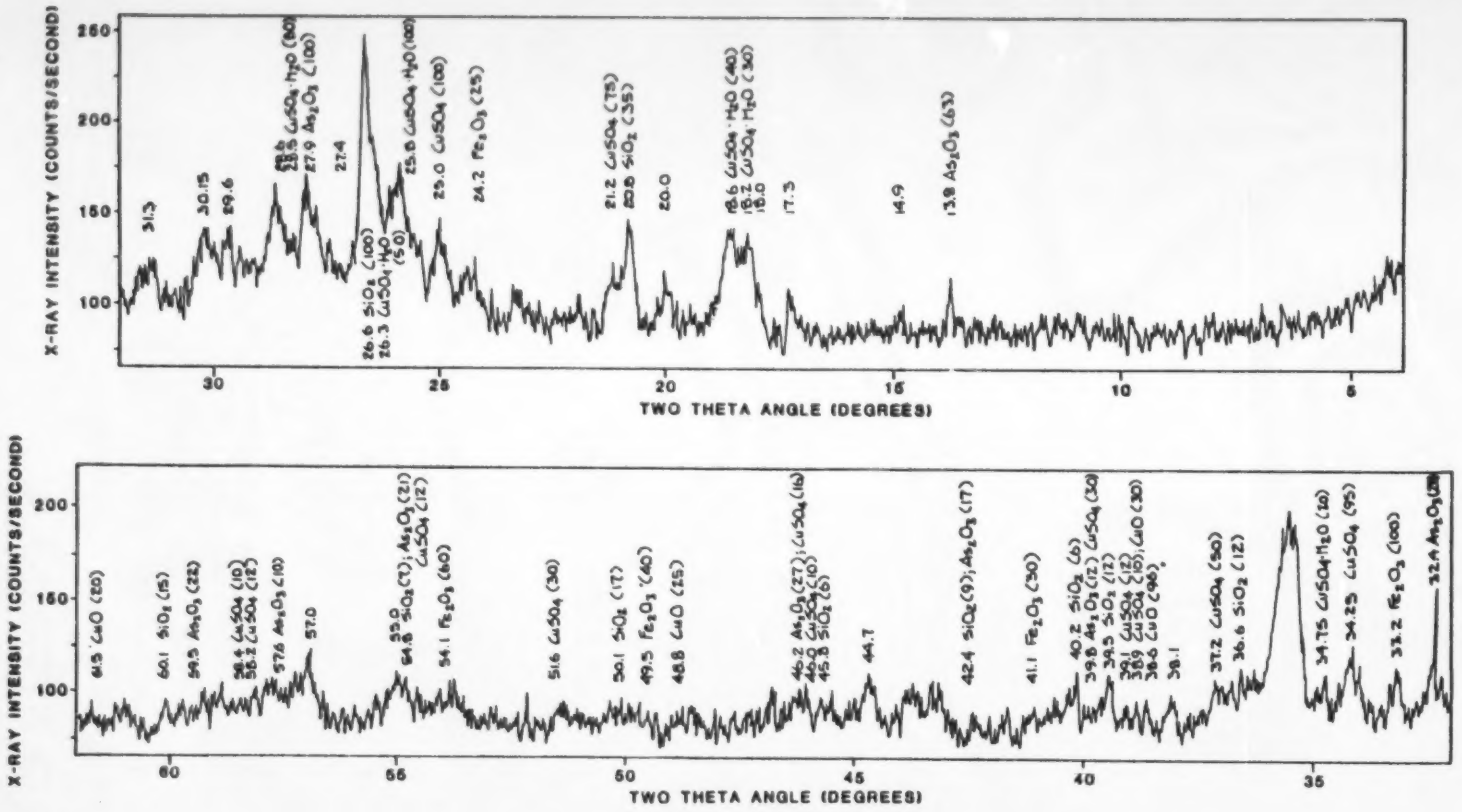


Figure 13-2. X-Ray Powder Diffraction Pattern - Dust Hopper (Collected July 11, 1976).

TABLE 13-2. X-RAY POWDER DIFFRACTION PATTERN - DUST HOPPER (SAMPLE #806)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES											
			α-Quartz SiO_2		Arsenolite As_2O_3		Chalcocyanite $CuSO_4$		Copper Sulfate Hydrate $CuSO_4 \cdot H_2O$		Hematite α-Fe_2O_3		Tenorite CuO	
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 6$	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 20$	d Angstroms	$I/I_o \geq 25$	d Angstroms	$I/I_o \geq 20$
13.8	35	6.39			6.39	63								
14.9	22	5.93												
17.3	30	5.11												
18.0	30	4.91												
18.2	60	4.86							4.87	30				
18.6	60	4.76							4.79	40				
20.0	35	4.43												
20.8	65	4.26	4.26	35										
21.2	45	4.18					4.187	75						
24.2	33	3.67									3.66	25		
25.0	45	3.555					3.549	100						
25.7	42	3.466							3.46	30				
25.8	70	3.446							3.43	100				
[26.3	45	3.379]							3.38	80				
26.6	140	3.345	3.343	100										
27.4	22	3.249												
27.9	57	3.192			3.195	100								
28.5	38	3.124							3.14	80				
28.6	50	3.116												
29.6	28	3.013												
30.15	33	2.964												
31.3	27	2.853												
32.4	35	2.759			2.768	28								
33.2	35	2.694									2.69	100		
34.25	45	2.618					[2.616 2.611]	95						
34.75	30	2.581							2.58	35				
[35.3	48	2.537]			2.541	38								
35.6	125	2.518											[2.530	49
[35.7	113	2.509]									2.51	50	2.523	100
36.6	35	2.452	2.458	12										

(Continued)

TABLE 13-2. X-RAY POWDER DIFFRACTION PATTERN - DUST HOPPER (SAMPLE #806)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES											
			α-Quartz SiO_2		Arsenolite As_2O_3		Chalcocyanite $CuSO_4$		Copper Sulfate Hydrate $CuSO_4 \cdot H_2O$		Hematite α-Fe_2O_3		Tenorite CuO	
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 6$	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 20$	d Angstroms	$I/I_o \geq 25$	d Angstroms	$I/I_o \geq 20$
37.2	30	2.411					[2.421							
38.1	22	2.359					: 416]	50						
38.6	20	2.328					2.321	10						
													2.323	96
38.9	18	2.310												
39.1	17	2.299											2.312	30
39.5	35	2.279	2.282	12			2.301	12						
39.8	7	2.262			2.262	12								
40.2	38	2.240	2.237	6					2.26	30				
41.1	20	2.192												
											2.201	30		
42.4	12	2.132	2.128	9	2.132	17								
44.7	35	2.025												
45.8	22	1.979	1.980	6										
46.05	32	1.969												
46.2	11	1.957			1.957	27	1.971	10						
							1.963	16						
48.8	17	1.863												
49.5	15	1.838											1.866	25
50.1	20	1.819	1.817	17										
											1.838	40		
51.6	10	1.768												
54.1	25	1.692					1.775	30						
54.8	30	1.674	1.672	7	1.670	21	1.674	12			1.690	60		
55.0	35	1.668												
57.0	42	1.614												
57.6	7	1.599			1.599	10								
58.2	25	1.583												
58.4	15	1.578												
59.5	5	1.551					1.584	12						
							1.581	10						
60.1	15	1.538	1.541	15										
61.5	10	1.505												
													1.505	20

Brackets [ ] indicate unresolved peaks.

The source for the standard patterns was the X-Ray Powder Diffraction Data File. The following cards were used:

Chemical Formula	Card No.
SiO_2	5-490
As_2O_3	4-566
$CuSO_4$	15-775
$CuSO_4 \cdot H_2O$	12-782
α-Fe_2O_3	13-534
CuO	

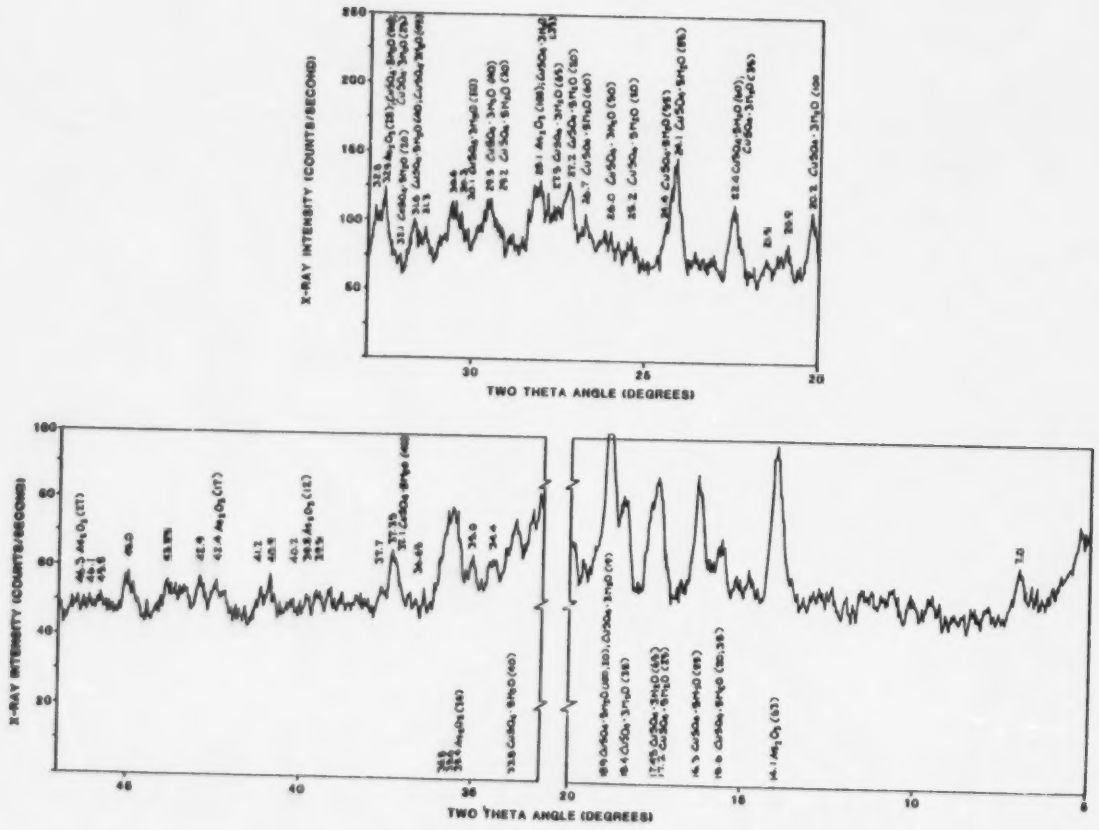


Figure 13-3. X-Ray Powder Diffraction Pattern - Collected at ESP Outlet on In-Stack Filter (Collected July 10, 1976, from 6:30 to 8:14 am).

TABLE 13-3. X-RAY POWDER DIFFRACTION PATTERN - COLLECTED AT ESP OUTLET ON IN-STACK FILTER (COLLECTED JULY 10, 1976 FROM 6:30 TO 8:14 AM)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES							
			Arsenolite As_2O_3		Copper Sulfate Pentahydrate $CuSO_4 \cdot 5H_2O$		Bonatite $CuSO_4 \cdot 3H_2O$			
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 20$	d Angstroms	$I/I_o \geq 19$	d Angstroms	$I/I_o \geq$
7.0	16	12.6								
14.1	48	6.27	6.394	63						
15.6	20	5.68			5.73 5.68	35 20				
16.3	37	5.43			5.48	55				
17.2	11	5.15			5.15	25				
17.45	36	5.08					5.09	65		
18.4	29	4.82					4.83	35		
18.9	55	4.69			4.73 4.66	100 20	4.69	19		
20.2	36	4.39					4.40	100		
20.9	30	4.27								
21.0	22	4.23								
21.5	12	4.13								
22.4	55	3.97			3.99	60	1.96	35		
24.1	85	3.70			3.71	85				
24.4		3.65					3.65	55		
25.2	10	3.53			3.54	20				
26.0		3.42					1.42	50		
26.7	35	3.336			3.30	60				
27.2	52	3.276			3.26	20				
27.5		3.241					3.24	65		
28.1	50	3.173	3.195	100			3.18	35		
29.2	20	3.056			3.05	30				
29.5	40	3.025					3.00	40		
30.1	20	2.966					2.97	20		
30.3	35	2.948								
30.6	40	2.919								
31.3	26	2.855								

(Continued)

TABLE 13-3. X-RAY POWDER DIFFRACTION PATTERN - COLLECTED AT ESP OUTLET ON IN-STACK FILTER (COLLECTED JULY 10, 1976 FROM 6:30 TO 8:14 AM)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES							
			Arsenolite As_2O_3		Copper Sulfate Pentahydrate $CuSO_4 \cdot 5H_2O$		Bonatite $CuSO_4 \cdot 3H_2O$			
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 20$	d Angstroms	$I/I_o \geq 19$	d Angstroms	$I/I_o \geq$
31.6	33	2.829			2.824	40	2.814	45		
32.1	15	2.786			2.788	20				
32.5	62	2.753	2.768	28	2.749	50	2.743	25		
32.8	48	2.728								
33.8	16	2.649			2.662	40				
34.4	7	2.605								
35.0	11	2.561								
35.4	26	2.533	2.541	38						
35.6	27	2.520								
35.8	28	2.506					2.494	40		
36.0		2.493								
36.65	5	2.450								
37.1	10	2.421			2.418	40				
37.35	20	2.406								
37.7	9	2.383								
39.5	9	2.279					2.275	35		
39.8	7	2.262	2.262	12						
40.2	6	2.249								
40.9	14	2.204								
41.2	10	2.189								
42.4	11	2.130	2.132	17						
42.9	13	2.106								
43.85	12	2.062								
45.0	16	2.012								
46.1	9	1.966								
46.3	8	1.958	1.958	27						
47.3	10	1.919								

(Continued)

TABLE 13-3. X-RAY POWDER DIFFRACTION PATTERN - COLLECTED AT ESP OUTLET ON IN-STACK FILTER (COLLECTED JULY 10, 1976 FROM 6:30 TO 8:14 AM)

OBSERVED PEAKS			ASSIGNMENT OF CRYSTALLINE SPECIES							
			Arsenolite As_2O_3		Copper Sulfate Pentahydrate $CuSO_4 \cdot 5H_2O$		Bonatite $CuSO_4 \cdot 3H_2O$			
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 10$	d Angstroms	$I/I_o \geq 20$	d Angstroms	$I/I_o \geq 19$	d Angstroms	$I/I_o \geq$
48.2	20	1.886								
48.8	13	1.864								
49.3	15	1.846								
49.8	16	1.829								
50.1	10	1.819								
50.4	11	1.809								

The Source for the Standard Patterns was the X-Ray Powder Diffraction File. The following cards were used:

Chemical Formula	Card No.
As_2O_3	4-566
$CuSO_4 \cdot 5H_2O$	11-646
$CuSO_4 \cdot 3H_2O$	12-262

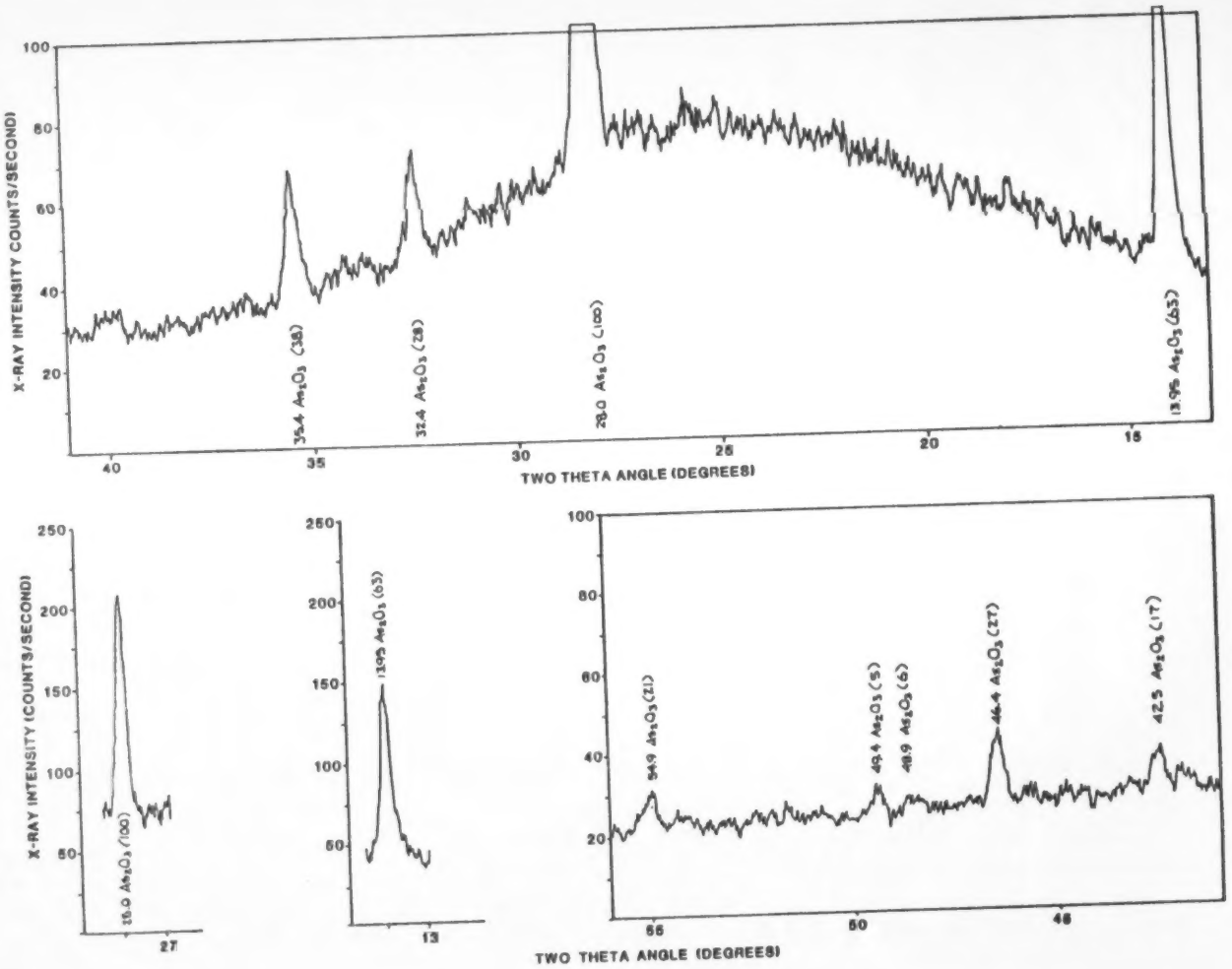


Figure 13-4. X-Ray Diffraction Pattern - Condensed Particulate Collected at ESP Outlet on Out-of-Stack Filter (July 15, 1976 from 8:50 to 10:20 am).

TABLE 13-4. X-RAY POWDER DIFFRACTION PATTERN - CONDENSED PARTICULATE COLLECTED AT ESP OUTLET ON OUT-OF-STACK FILTER (JULY 15, 1976, FROM 8:50 TO 10:20 AM)

OBSERVED PEAKS			CRYSTALLINE SPECIES	
			Arsenolite* As_2O_3	
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 5$
13.95	108	6.34	6.39	63
28.0	135	3.18	3.195	100
32.4	25	2.761	2.768	28
35.4	32	2.533	2.541	38
39.8	6	2.262	2.262	12
42.5	12	2.125	2.132	17
46.4	21	1.954	1.957	27
48.9	4	1.860	1.873	6
49.4	8	1.842	1.846	5
54.9	8	1.670	1.670	21

*Source: X-Ray Powder Diffraction Data File, Card No. 4-566.

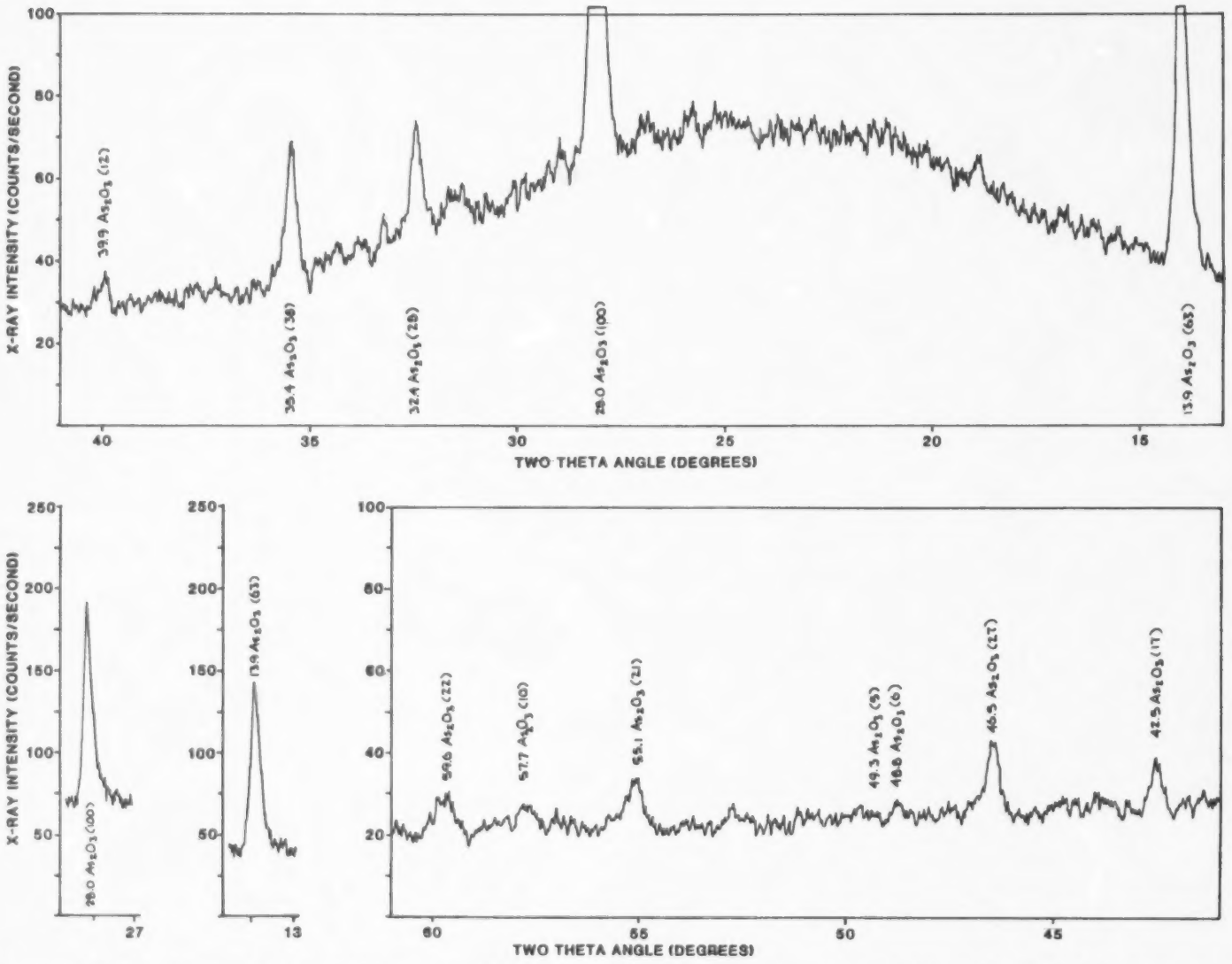


Figure 13-5. X-Ray Powder Diffraction Pattern - Condensed Particulate Collected at ESP Inlet on Out-of-Stack Filter (July 15, 1976 from 1:00 to 2:20 pm).

TABLE 13-5. X-RAY POWDER DIFFRACTION PATTERN - CONDENSED PARTICULATE COLLECTED AT ESP INLET ON OUT-OF-STACK FILTER (JULY 15, 1976, FROM 1:00 TO 2:00 PM)

OBSERVED PEAKS			CRYSTALLINE SPECIES	
			Arsenolite* As_2O_3	
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 5$
13.9	105	6.36	6.39	63
28.0	125	3.18	3.195	100
32.4	26	2.761	2.768	28
35.4	33	2.533	2.541	38
39.9	8	2.257	2.262	12
42.5	12	2.125	2.132	17
46.5	18	1.951	1.957	27
48.8	4	1.864	1.873	6
49.3	2	1.846	1.846	5
55.1	13	1.666	1.670	21
57.7	6	1.597	1.599	10
59.6	11	1.550	1.551	22

*Source: X-Ray Powder Diffraction Data File, Card No. 4-566.

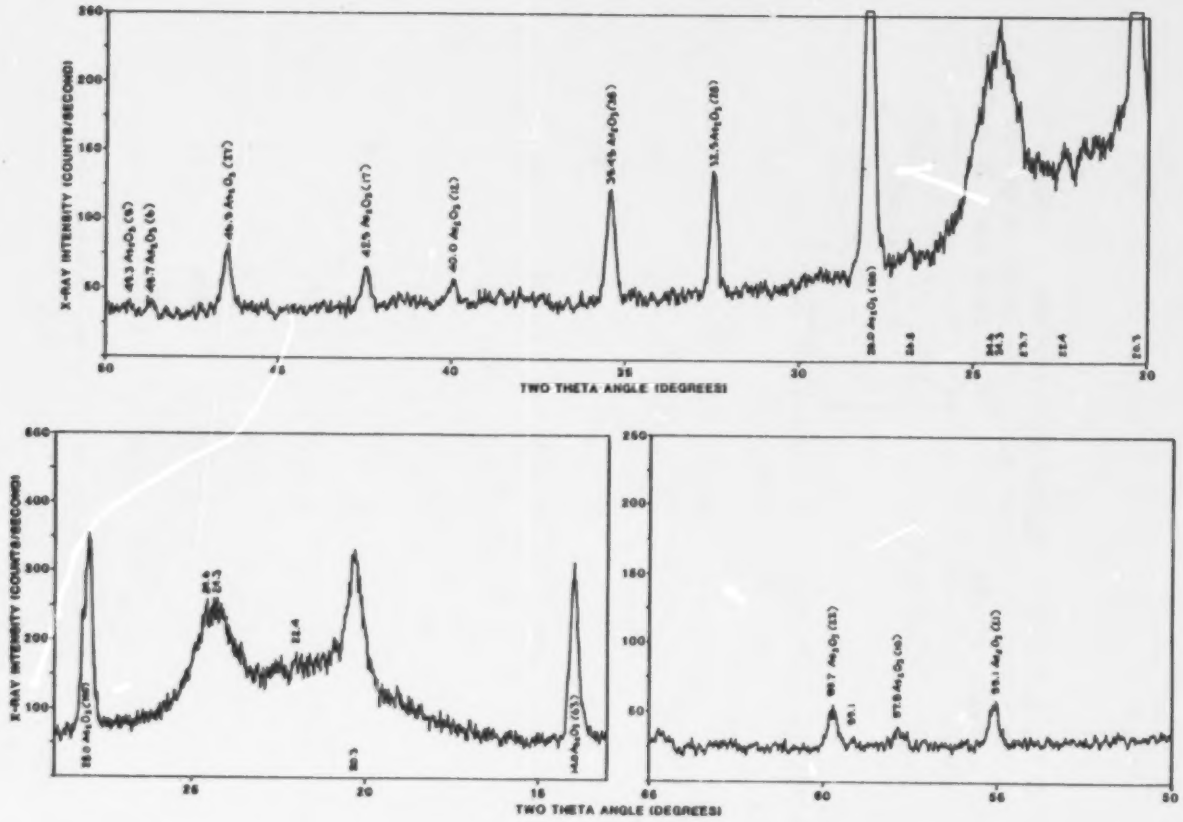


Figure 13-6. X-Ray Powder Diffraction Pattern for Material Condensed in Impingers (Composite Sample).

TABLE 13-6. X-RAY POWDER DIFFRACTION PATTERN FOR MATERIAL CONDENSED IN IMPINGERS (COMPOSITE SAMPLE)

OBSERVED PEAKS			CRYSTALLINE SPECIES	
			Arsenolite As_2O_3	
2θ Degrees	I Counts/Sec	d Angstroms	d Angstroms	$I/I_o \geq 5$
14.0	260	6.32	6.394	63
20.3	215	4.372		
22.4	30	3.966		
23.7	70	3.751		
24.3	135	3.660		
24.6	140	3.617		
26.8	18	3.324		
28.0	280	3.184	3.195	100
32.5	92	2.753	2.768	28
35.45	85	2.5295	2.541	38
40.0	20	2.252	2.262	12
42.5	32	2.125	2.132	17
46.5	50	1.951	1.957	27
48.7	10	1.867	1.873	6
49.3	10	1.846	1.846	5
55.1	33	1.666	1.670	21
57.8	15	1.594	1.599	10
59.1	6	1.561		
59.7	28	1.547	1.551	22
64.6	14	1.441	1.442	12
64.8	15	1.438		

TABLE 13-7. SUMMARY OF CRYSTALLINE SPECIES IDENTIFIED BY X-RAY DIFFRACTION

Sample Designation	α-Quartz SiO_2	Chalcopyrite $CuFeS_2$	Arsenolite As_2O_3	Chalcocyanite $CuSO_4$	Copper Sulfate Hydrate $CuSO_4 \cdot H_2O$	Bonatite $CuSO_4 \cdot 3H_2O$	Copper Sulfate Pentahydrate $CuSO_4 \cdot 5H_2O$	Hematite α-Fe_2O_3	Tenorite CuO
Reverberatory Furnace Feed Concentrate	present	present							
Dust Hopper	present		present	present	present			probably present	probably present
In-Stack Filter (Outlet)			present			present	present		
Out-of-Stack Filter (Outlet, White Color)			present						
Out-of-Stack Filter (Inlet, Run #2, Black Color)			present						
Material Condensed in Impinger (Inlet/Outlet Composite)			present						

SECTION 14

ANALYTICAL RESULTS OF VAPOR TRAIN SAMPLING

The temperature of matte and slag in a reverberatory furnace ranges typically from 1950-2300°F. Certain chemical compounds are vaporized at this temperature. The temperature of the flue gas is lowered to 600°F in waste heat boilers.

The vapor train shown in Figure 14-1 was built to determine which compounds are still in the flue gas as vapors at this temperature. This train was used to collect a vapor sample as the outlet of the electrostatic precipitator on July 16, 1977. A pyrex nozzle was attached to a pyrex-lined, heat traced probe. The probe was connected to an out-of-stack oven kept at duct temperature. The oven housed a cyclone followed by a filter. The impinger train following the out-of-stack oven was the same as that used for the integral WEP train. The cyclone-filter arrangement retained particulates. The impinger train collected species condensable between 600°F and 32°F.

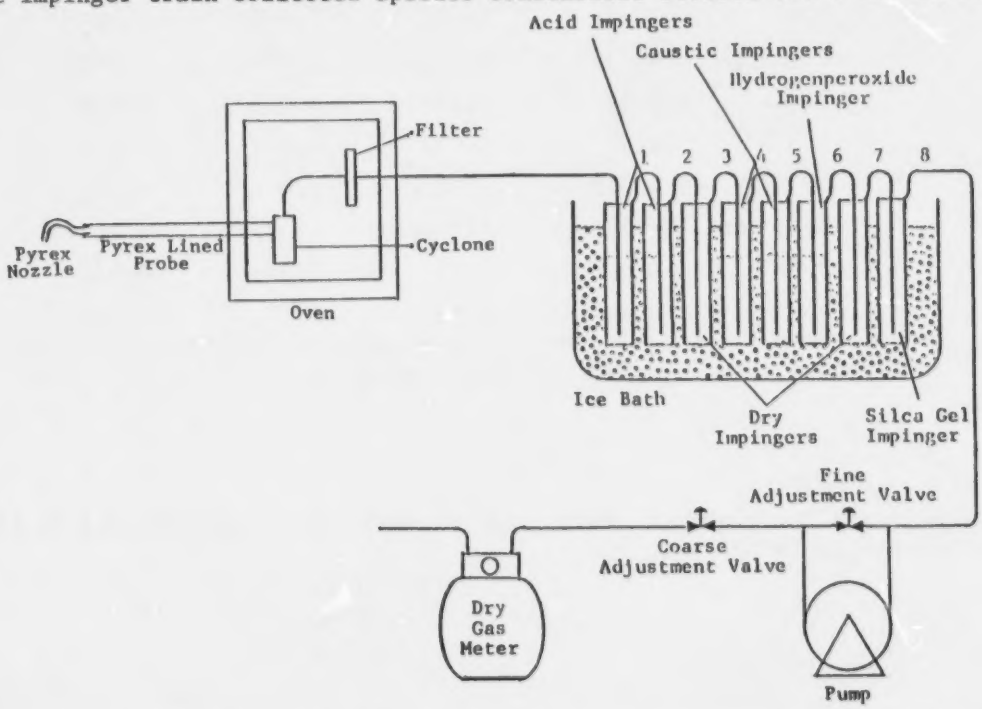


Figure 14-1. Schematic of the Vapor-Phase Trace Element Sampling Train.

Approximately 129 cubic feet (at 60°F, 29.92" Hg and dry) were collected using the vapor phase sampling train. After trapping all particulate matter at stack temperature, the remaining vapors were condensed in the series of five impinger solutions. Table 14-1 gives the analytical results for each element in units of µg/gram of analytical solution.

TABLE 14-1. ANALYTICAL RESULTS FROM VAPOR TRAIN SAMPLING

	1st acid Impinger	2nd acid Impinger	1st basic Impinger	2nd basic Impinger	Peroxide Impinger
As	61	150	24	41	29
Ba	1.1	1.4	1.4	1.5	<.5
Be	<.02	<.02	<.02	<.02	<.02
Cd	0.0010	0.0010	<.001	<.001	<.001
Cr	0.11	0.17	0.18	0.22	0.16
Cu	14	38	0.19	0.24	0.20
F	55	120	13	8.9	0.42
Fe	1.1	1.3	0.69	0.74	<.01
Hg	0.45	0.62	0.61	<.001	<.001
Mo	0.025	0.039	0.0080	0.0065	0.0080
Ni	0.085	0.13	0.074	0.071	0.016
Pb	0.058	0.097	<.001	<.001	<.001
Sb	0.039	0.018	<.01	<.01	0.026
Se	1080 ppb	1590 ppb	550 ppb	580 ppb	630 ppb
V	0.095	0.099	0.13	0.045	0.058
Zn	0.17	0.16	0.20	0.22	0.025

Note: all values in µg/g unless otherwise noted

Table 14-2 gives the elemental flow rates as vapor or non-particulate based on the results in Table 14-1.

TABLE 14-2. FLOW RATES OF GASEOUS EMISSIONS

Element	Flow Rate lb/hr	Element	Flow Rate lb/hr
As	15	Hg	0.062
Ba	0.27	Mo	0.016
Be	$<4 \times 10^{-3}$	Ni	0.031
Cd	1.1×10^{-4}	Pb	8.7×10^{-3}
Cr	0.036	Sb	3.0×10^{-3}
Cu	2.94	Se	0.21
F	11.0	V	0.020
Fe	0.196	Zn	0.036

SECTION 15

ARSENIC SAMPLING

The sampling methodology and equipment used were specified by the Environmental Protection Agency Office of Air Quality Planning and Standards. This section describes details of the approach used to collect the samples for arsenic determination.

EQUIPMENT DESCRIPTION

A modified EPA Method 5 sampling train, shown schematically in Figure 15-1, was used for this sampling effort. The front half of the train was conventional and consisted of a stainless steel nozzle, pyrex-lined probe, cyclone, and filter holder with a glass-fiber filter. The back half of the train was different from that normally used for EPA Method 5 sampling. It consisted of six impingers; the first, second, third, and sixth impingers had straight or modified tips while the fourth and fifth were standard Smith-Greenburg impingers. The first three impingers contained 250 ml of 10% hydrogen peroxide solution. Impingers 4 and 5 contained 250 ml of 0.1N sodium hydroxide. The sixth impinger which removed moisture from the gas stream contained dry preweighed silica gel.

Lear Siegler Inc. Model PM/100 manual stack samplers were used. The control console of this equipment contains all controls, temperature and pressure indicators. The vacuum pump contained in the control console is a two cylinder diaphragm pump rated at three acfm at fifteen inches of mercury.

The pressure differential across the flow rate metering orifice, ΔH, is measured with a 0-10" H_2O magnehelic gauge. The pressure differential generated by the S-type pitot is measured with a 0-5" H_2O magnehelic gauge or a 0-0.5" H_2O inclined manometer. The stack temperature was monitored using Type K, chromel-alumel, thermocouples and a digital indicating pyrometer.

The glassware was as specified by EPA Method 5; however, to minimize clean-up time the cyclone was not used prior to the filter at the ESP outlet.

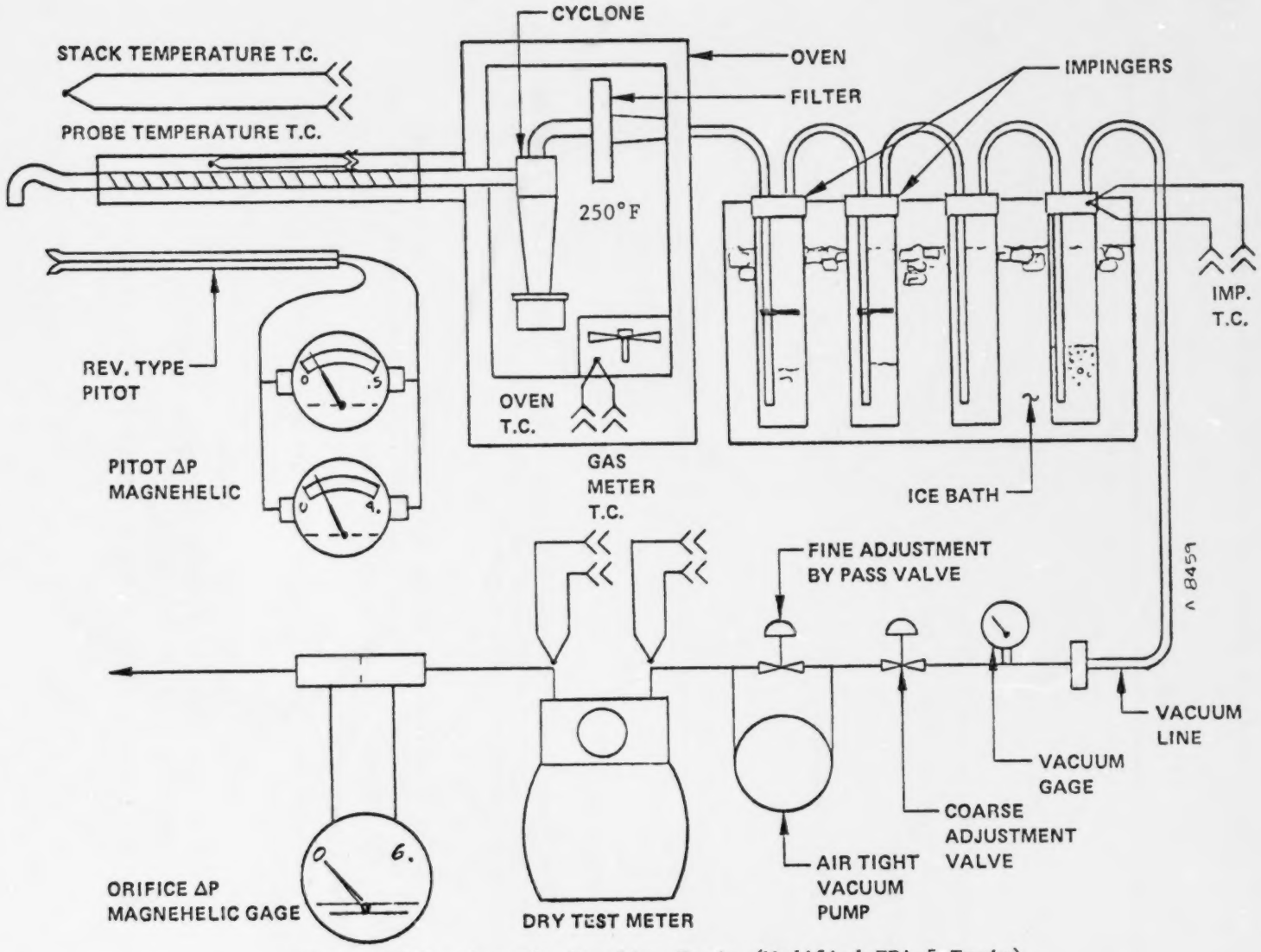


Figure 15-1. Arsenic Sampling Train (Modified EPA-5 Train).
Note: Six impingers were used.

The dry gas meters, the flow rate orifice, and the S-type pitot of each sampling train were calibrated by Lear Siegler's manufacturing agent, Napp Inc. of Austin, Texas. A summary of these calibration results is presented in Table 15-1.

TABLE 15-1. SUMMARY OF CALIBRATION DATA

Unit	D313	D314
Calibration Date	6-11-76	6-11-76
Dry gas meter correction factor γ (ratio of standard flow to dry gas meter flow)	1.0011	0.9955
$\Delta H@$ (orifice pressure drop @ .75 cfm, 29.92" Hg, 70°F)	1.86	1.82
Pitot tube correction factor	0.85	0.85

SAMPLING METHODOLOGY

Three runs were made sampling simultaneously at the inlet and outlet of the electrostatic precipitator servicing the reverberatory furnace, using methodology described by EPA Method 5.

Prior to sampling, the trains were thoroughly cleaned then rinsed with dilute ultra-high purity nitric acid. The reagents used in the train clean-up and impinger solutions were reagent grade.

The sample was recovered after each run and stored in five segments as follows:

- 1 - filter plus 50 ml of 0.1N NaOH,
- 2 - probe and filter holder washings, deionized water and 0.1N Ultrex, HNO_3,
- 3 - contents of impingers 1 through 3, (10% H_2O_2),

- 4 - contents of impinger 4, (0.1N NaOH), and
- 5 - contents of Impinger 5, (0.1N NaOH).

The specified clean-up procedure, an initial rinse with deionized water followed by a second rinse with 0.1N nitric acid, did not remove all of the sample collected. A red substance, oily in appearance, condensed in the sample line downstream of the filter oven. The majority of this substance was contained in the glass connector prior to the first impinger. However, it was also visible on the down spout and walls of the first impinger.

Subsequent attempts to recover this condensed residue using deionized water and nitric acid were unsuccessful. As specified in instructions from EPA/OAQPS, no acetone was used in the attempted sample recovery.

A decision was made after consultation with EPA/OAQPS to allow the condensed residue not removed by the specified sample recovery scheme to accumulate in the glassware and to recover it if possible at the completion of the three sampling runs.

The quantity of condensed residue which was collected at the ESP inlet appeared to be significantly less than that collected at the outlet. For this reason, the residue collected by the inlet train was used to determine which sample recovery methods would be most effective and thus was not completely recovered.

The recovered condensed residue from the outlet sampling train was returned to the laboratory in a polyethylene bottle together with the reagents used in the recovery attempts. A nylon bristled brush was found to be the most efficient in the recovery of the residue. However, it too became coated with the material and as a result was also included in the sample which was returned to the laboratory for analysis. Recovery of the condensed residue was not quantitative.

RESULTS

The results for each of the six arsenic sampling runs are in Table 15-2. The emission rates are based on sampling data collected by Radian personnel and the arsenic concentration of the analytical samples, as reported by Battelle, Columbus Laboratories, Columbus, Ohio. The analytical results were received by Radian Corporation through EPA/IERL in February, 1977.

The quantity of arsenic present in the condensed residue recovered from the glassware following the filter oven of the outlet sampling train

TABLE 15-2. SUMMARY OF ARSENIC EMISSION DATA FROM THE REVERBERATORY ELECTROSTATIC PRECIPITATOR

		INLET DUCT			OUTLET DUCT		
Run	Date	Time (min)	Gas Flow Rate (acfm)	Arsenic Flow Rate (lbs/hr)	Time (min)	Gas Flow Rate (acfm)	Arsenic Flow Rate (lbs/hr)
1	7-13-76	0930-1226	155200	59.3	0951-1336	170700	53.7
2	7-14-76	0555-0907	156000	72.9	0610-0855	168900	44.8
3	7-14-76	1132-1505	157900	75.4	1130-1415	166500	51.3
Average		-	156400	69.2	-	168700	49.9

was determined by Radian Corporation. This was accomplished by acid dissolution and direct aspiration into the flame of an atomic absorption instrument. The quantity of arsenic present in the recovered residue was 0.1441 g.

The average arsenic emission rate from the electrostatic precipitator was determined from these tests to be 49.9 lbs/hr. Arsenic entered the ESP at a rate of 69.2 lbs/hr. The difference, 19.3 lbs/hr, is the amount collected by the ESP in the form of dust. This value compares with 30 lbs/hr arsenic collection rate determined in the ESP element balance attempt (July 11, 1976).

All pertinent data measured and calculated follow.

TABLE 15-3. SUMMARY OF ARSENIC SAMPLING DATA REVERBERATORY FURNACE ELECTROSTATIC PRECIPITATOR INLET

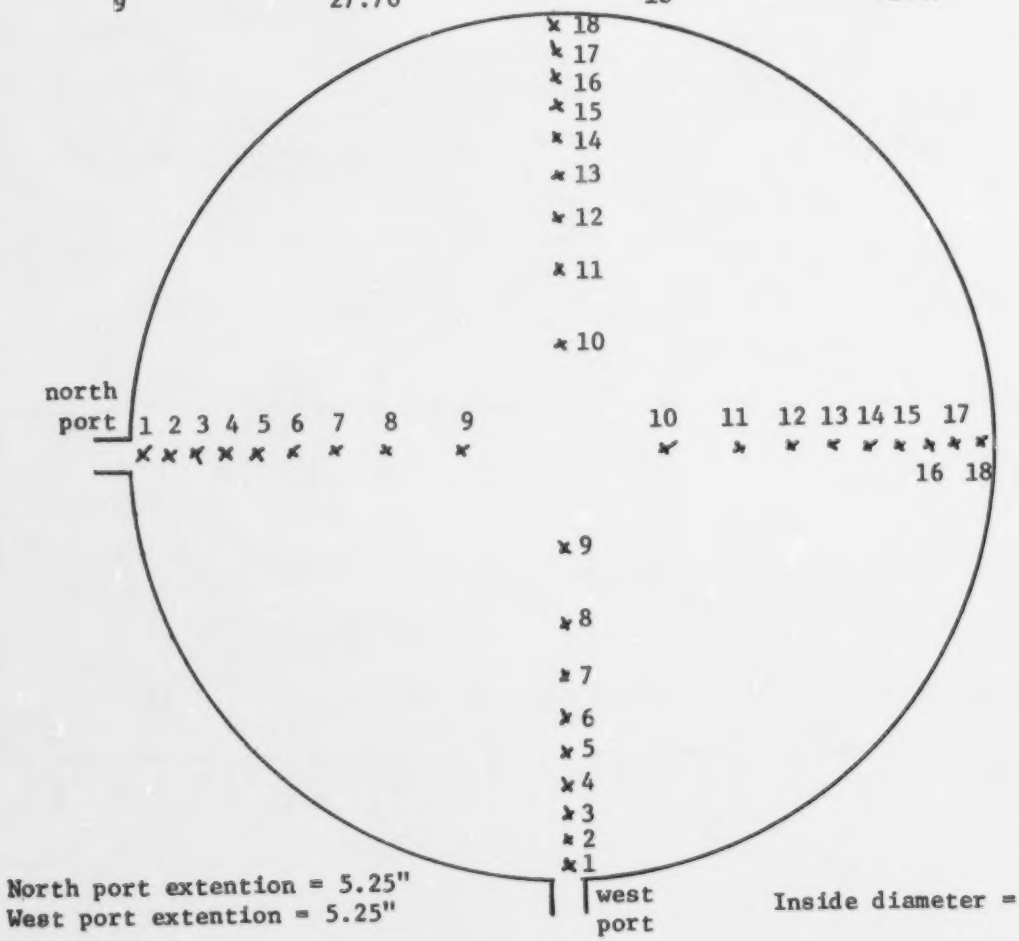
Run	1	2	3
Date	7-13-76	7-14-76	7-14-76
Time	0930-1226	0555-0907	1132-1505
Duration, (min)	120	120	120
Metered volume, (ft^3)	42.66	42.31	42.63
Corrected metered volume, (ft^3)	42.47	42.12	42.44
Average meter temperature, (^oR)	577	572	589
Average stack temperature, (^oR)	1082	1062	1099
Barometric pressure, (in. Hg)	28.20	28.20	28.20
Stack pressure, (in. Hg)	28.12	28.13	28.13
Moisture collected, (gm)	167.3	171.9	144.1
Dry gas fraction	0.823	0.814	0.840
Average molecular weight, (gm/gm-mole)	27.48	27.38	27.68
Average $(\Delta P x T_s)^{\frac{1}{2}}$	20.62	20.69	21.06
Average gas velocity, (ft/sec)	53.90	54.17	54.84
Flue gas flow rate, (acfm)	155232	156004	157931
Nozzle area, (ft^2)	1.623×10^{-4}	1.623×10^{-4}	1.623×10^{-4}
Sample volume @ stack conditions, (ft^3)	97.04	96.31	94.51
Percent of isokinetic, (%)	154	152	147
Arsenic collected, (gm)	0.280	0.340	0.341
Arsenic flow rate, (lbs/hr)	59.25	72.85	75.40

TABLE 15-4. SUMMARY OF ARSENIC SAMPLING DATA REVERBERATORY FURNACE ELECTROSTATIC PRECIPITATOR OUTLET

Run	1	2	3
Date	7-13-76	7-14-76	7-14-76
Time	0951-1336	0610-0855	1130-1415
Duration, (min)	120	120	120
Metered volume, (ft^3)	76.80	75.96	71.65
Corrected metered volume, (ft^3)	76.88	76.04	71.73
Average meter temperature, (^oR)	572	574	563
Average stack temperature, (^oR)	1055	1070	1040
Barometric pressure, (in. Hg)	28.20	28.20	28.20
Stack pressure, (in. Hg)	28.02	28.02	28.02
Moisture collected, (gm)	255.4	254.6	--
Dry gas fraction	.847	.846	.865
Average molecular weight, (gm/gm-mole)	27.84	27.31	28.05
Average $(\Delta P x T_s)^{\frac{1}{2}}$, (in. $H_2O \cdot {}^oR)^{\frac{1}{2}}$	38.15	37.38	37.35
Average gas velocity, (ft/sec)	99.25	98.18	96.80
Flue gas flow rate, (acfm)	170720	168880	166506
Nozzle area, (ft^2)	1.623×10^{-4}	1.623×10^{-4}	1.623×10^{-4}
Sample volume @ stack conditions, (ft^3)	168.49	168.63	154.17
Percent of isokinetic, (%)	145	147	136
Arsenic collected, (gm)	.352	.289	.313
Arsenic collected as condensed residue, (gm)	.049	.049	.046
Total arsenic collected	.401	.338	.359
Arsenic emission rate (lbs/hr)	53.74	44.78	51.29

TRAVERSE POINTS LAYOUT FOR REVERBERATORY ELECTROSTATIC PRECIPITATOR OUTLET FOR ARSENIC SAMPLING

Point No.	Distance from Inside Wall	Point No.	Distance from Inside Wall
1	1.02"	10	44.81"
2	3.19"	11	51.04"
3	5.44"	12	55.39"
4	7.90"	13	58.87"
5	10.59"	14	61.92"
6	13.63"	15	64.60"
7	17.11"	16	67.06"
8	20.52"	17	69.31"
9	27.70"	18	71.49"



North port extention = 5.25"
West port extention = 5.25"

Inside diameter = 72.5"

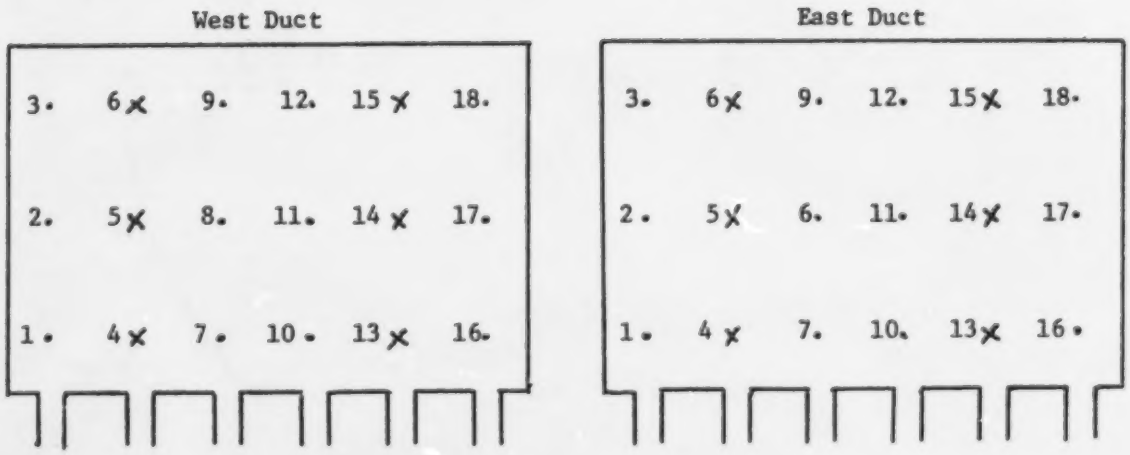
TRAVERSE POINTS LAYOUT FOR REVERBERATORY ELECTROSTATIC PRECIPITATOR INLET

Point Numbers	Distance from Port Wall
1, 4, 7, 10, 13, & 16	8"
2, 5, 8, 11, 14, & 17	24"
3, 6, 9, 12, 15, & 18	40"

Note:
- ports are on 12" centers only
- only points denoted with an "x" were sampled during arsenic test
- ports are on 12' centers

West duct 4' x 6'

East duct 4' x 6'



FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 13, 1976 Filter No. -

Sample No. As #1 Bar. Press. "Hg" 28.20 Oper. Rohlack

Meter No. E-313 Stack Press. "H_2O" 28.02 Probe No. 6 ft.

Nozzle No. 3/16 Orifice Constants: a ____ b ____ PTCF .85

Nozzle Area (ft^2) 1.632×10^{-4} Δp 1.25 ΔH 0.89 (in. H_2O) K .708

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_s in. H_2O	$\Delta H_@$ in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
17	0951	172.16	1.25	0.89	0.89	110	99	14.0	250	580
17	0954	173.90	1.25	0.89	0.89	112	98	13.8	250	579
16	0957	175.86	1.30	0.93	0.93	116	98	13.8	250	575
16	1000	178.20	1.30	0.93	0.93	117	98	13.8	250	573
15	1003	189.21	1.35	0.97	0.97	120	98	13.8	250	572
15	1006	182.23	1.38	0.99	0.99	120	98	14.8	250	572
14	1009	184.25	1.45	1.04	1.04	120	98	15.3	250	576
13	1012	186.33	1.50	1.07	1.07	120	99	15.8	250	579
12	1015	188.43	1.55	1.11	1.11	120	100	15.8	250	581
11	1018	190.51	1.55	1.11	1.11	121	100	16.2	250	591
10	1021	192.62	1.50	1.07	1.07	121	101	16.8	250	616
9	1024	194.71	1.48	1.06	1.06	120	101	16.7	250	616
8	1027	196.80	1.40	1.00	1.00	120	101	16.8	250	615
7	1030	198.88	1.35	0.97	0.97	120	101	16.8	250	615
6	1033	200.96	1.30	0.93	0.93	120	101	16.5	250	615
5	1036	203.00	1.25	0.89	0.89	121	101	15.1	250	615
4	1039	204.95	1.20	0.86	0.86	122	101	15.1	250	602
3	1042	206.92	1.10	0.79	0.79	123	101	15.1	250	615

Total Sample Time 120 Min.

Avg. Meter Temp. 112 °F

Avg. Stack Temp. 595 °F

Corrected Sample Vol. at Meter Conditions

(76.80) x (1.001)

(Net Vol) (D.G.M.C.F.)

76.88 ft^3

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 13, 1976 Filter No. _____

Sample No. As #1 (Contd) Bar. Press. "Hg" _____ Oper. Rohlack

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: a _____ PTCF _____
b _____

Nozzle Area _____ Δp _____ ΔH _____ K _____
(ft^2) (in. H_2O)

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
2	1045	208.85	0.85	0.61	0.61	124	101	11.2	250	615
1	1048	210.65	0.80	0.57	0.57	127	102	11.0	250	615
16	1235	212.28	1.50			115	110	18.0	250	584
15	1241	216.45	1.46			118	107	18.0	250	580
14	1247	220.59	1.49			120	108	18.0	250	582
13	1253	224.47	1.50			123	108	18.4	250	582
12	1300	228.68	1.55			125	109	18.8	250	586
11	1306	232.45	1.65			124	110	20.0	250	593
10	1312	236.08	1.65			122	110	20.0	250	607
9	1318	239.60	1.60			129	110	29.9	250	611
8	1324	242.90	1.60			119	110	29.5	250	612
7	1330	245.98	1.55			119	110	21.0	250	615
	1336	248.96								

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

Corrected Sample Vol. at Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

Sample No. As-1-0

Impinger No.	Solution Used	Imp. Tip Configuration	Weight (grams)	
#1	10% H_2O_2	st	Final	858.5
			Initial	695.6
			Wt. gain	162.9
#2	10% H_2O_2	st	Final	767.8
			Initial	700.9
			Wt. gain	66.9
#3	10% H_2O_2	st	Final	683.4
			Initial	677.8
			Wt. gain	5.6
#4	0.1N NaOH	sg	Final	697.5
			Initial	696.0
			Wt. gain	1.5
#5	0.1N NaOH	sg	Final	672.9
			Initial	677.9
			Wt. gain	-5.0 *
#6	Silica gel	st	Final	664.8
			Initial	641.3
			Wt. gain	23.5

TOTAL WEIGHT GAIN OF IMPINGERS (grams) 255.4

* indicates that part of the impinger solution was entrained into the next impinger.

ORSAT ANALYSIS RESULTS

Date: _____

Time: _____

	Gas Fractional Part
CO_2	
O_2	
CO	
N_2	

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Inlet East

Date July 13, 1976 Filter No.

Sample No. As #1 Bar. Press. "Hg" 28.20 Oper. Fuchs

Meter No. E-314 Stack Press. "H_2O" 28.12 Probe No. 6 ft.

Nozzle No. Orifice Constants: a b PTCF

Nozzle Area 1.632×10^{-4} (ft^2) Δp .30 ΔH (in. H_2O) K .83

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
	0930	304.26	0.30	0.25	0.25					
13	0935	305.74	0.30	0.25	0.25	114	96	4.2	250	539
13	0940	307.30	0.30	0.25	0.25	121	97	4.0	250	538
14	0945	309.29	0.48	0.40	0.40	126	98	5.1	250	564
14	0950	311.28	0.48	0.40	0.40	129	100	5.3	250	578
15	0955	313.29	0.51	0.42	0.42	131	101	6.0	250	597
15	1000	315.31	0.51	0.42	0.42	137	107	6.5	250	595
	1006		0.25	0.20	0.20					
4	1011	316.62	0.25	0.20	0.20	131	105	5.3	250	600
4	1016	317.92	0.25	0.20	0.20	123	110	7.1	250	610
5	1021	319.83	0.53	0.44	0.44	134	106	14.7	250	618
5	1026	321.94	0.53	0.44	0.44	131	104	15.0	250	614
6	1031	324.09	0.55	0.46	0.46	129	105	17.0	250	632
6	1036	326.24	0.55	0.46	0.46	128	106	17.3	250	641

Total Sample Time 120 Min.

Avg. Meter Temp. 117 °F

Avg. Stack Temp. 622 °F

Corrected Sample Vol. at Meter Conditions

(42.66) x (0.9955)

(Net Vol) (D.G.M.C.F.)

= 42.47 ft^3

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name West Inlet

Date July 13, 1976 Filter No. _____

Sample No. As #1 (Contd) Bar. Press. "Hg" _____ Oper. Fuchs

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: a _____ b _____ PTCF _____

Nozzle Area _____ (ft^2) Δp _____ ΔH _____ (in. H_2O) K _____

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F	
				Desired	Actual	Inlet	Outlet				
	1120	376.24	0.17	0.14	0.14						
13	1125	327.53	0.17	0.14	0.14	125	103	3.5	250	640	
13	1130	328.84	0.17	0.14	0.14	129	103	3.5	250	635	
14	1135	330.72	0.45	0.37	0.37	132	103	4.9	250	657	
14	1140	332.66	0.45	0.37	0.37	134	103	4.9	250	664	
15	1145	334.68	0.49	0.41	0.41	135	104	5.3	250	683	
15	1150	336.72	0.49	0.41	0.41	135	104	5.3	250	672	
	1156	336.72	0.19	0.16	0.16						
4	1201	337.95	0.20	0.165	0.165	132	105	3.5	250	624	
4	1206	339.15	0.20	0.165	0.165	133	105	3.5	250	614	
5	1211	340.94	0.44	0.36	0.36	136	106	5.0	250	646	
5	1216	342.84	0.44	0.36	0.36	140	108	5.0	250	650	
6	1221	344.86	0.49	0.41	0.41	141	109	6.0	250	669	
6	1226	346.92	0.49	0.41	0.41	141	109	6.0	250	656	STOP

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

Corrected Sample Vol. at Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

Sample No. As-1-I

Impinger No.	Solution Used	Imp. Tip Configuration	Weight (grams)	
#1	10% H_2O_2	st	Final	762.9
			Initial	663.7
			Wt. gain	99.5
#2	10% H_2O_2	st	Final	694.9
			Initial	663.7
			Wt. gain	31.2
#3	10% H_2O_2	st	Final	682.3
			Initial	661.9
			Wt. gain	20.4
#4	0.1N NaOH	sg	Final	679.8
			Initial	677.3
			Wt. gain	2.5
#5	0.1N NaOH	sg	Final	674.4
			Initial	676.0
			Wt. gain	-1.6 *
#6	Silica gel	st	Final	659.1
			Initial	643.8
			Wt. gain	15.3

TOTAL WEIGHT GAIN OF IMPINGERS (grams) 167.3

* indicates that part of the impinger solution was entrained into the next impinger.

ORSAT ANALYSIS RESULTS

Date: _____

Time: _____

	Gas Fractional Part
CO_2	
O_2	
CO	
N_2	

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 14, 1976 Filter No. _____

Sample No. As #2 Bar. Press. "Hg" 28.20 Oper. Rohlack

Meter No. E-313 Stack Press. "H_2O" 28.02 Probe No. 6 ft.

Nozzle No. 3/16 Orifice Constants: a _____ PTCF _____
b _____

Nozzle Area (ft^2) 1.632×10^{-4} Δp 1.20 ΔH .85 (in. H_2O) K .708

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
17	0610	248.96	1.20	0.85	0.85	98	89	13.7	250	554
17	0613	250.90	1.18	0.84	0.84	103	89	13.4	250	555
16	0616	252.80	1.25	0.89	0.89	106	89	13.4	250	556
16	0619	254.695	1.25	0.89	0.89	107	89	13.4	250	555
15	0622	256.56	1.35	0.96	0.96	110	89	13.4	250	558
15	0625	258.425	1.35	0.96	0.96	111	90	14.2	250	557
14	0628	260.33	1.40	1.00	1.00	111	90	16.0	250	559
13	0631	262.29	1.45	1.03	1.03	111	90	16.0	250	561
12	0634	264.26	1.50	1.07	1.07	111	91	17.2	250	564
11	0637	266.27	1.55	1.10	1.10	110	91	17.2	250	575
10	0640	268.28	1.50	1.07	1.07	109	91	17.2	250	590
9	0643	270.29	1.45	1.03	1.03	110	91	17.2	250	593
8	0645	272.25	1.38	0.98	0.98	110	91	16.8	250	594
7	0649	274.21	1.33	0.95	0.95	112	92	16.8	250	595
6	0652	276.17	1.30	0.93	0.93	112	92	16.5	250	595
5	0655	278.11	1.28	0.91	0.91	114	93	16.3	250	596
4	0658	280.025	1.18	0.84	0.84	115	94	16.3	250	590
3	0701	281.97	1.04	0.74	0.74	115	94	16.1	250	590

Total Sample Time 120 Min.

Avg. Meter Temp. 103 °F

Avg. Stack Temp. 580 °F

Corrected Sample Vol. at Meter Conditions

(75.96) x (1.001)

(Net Vol) (D.G.M.C.F.)

76.04 ft^3

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 14, 1976 Filter No. _____

Sample No. As #2 (Contd) Bar. Press. "Hg" _____ Oper. _____

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: a _____ b _____ PTCF _____

Nozzle Area (ft^2) _____ Δp _____ ΔH (in. H_2O) _____ K _____

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
2	0704	283.83	1.04	0.74	0.74	116	94	15.8	250	590
1	0707	285.64	1.04	0.74	0.74	116	94	15.8	250	590
17	0755	287.43	1.35	0.96	0.96	108	100	16.9	250	566
17	0758	289.40	1.35	0.96	0.96	108	99	19.5	250	566
16	0801	291.27	1.35	0.96	0.96	106	98	19.7	250	570
16	0804	293.18	1.35	0.96	0.96	105	97	19.8	250	567
15	0807	295.12	1.35	0.96	0.96	106	97	19.8	250	566
15	0810	297.045	1.35	0.96	0.96	106	97	19.8	250	566
14	0813	298.975	1.35	0.96	0.96	107	97	19.8	250	566
13	0816	300.880	1.35	0.96	0.96	108	97	19.8	250	572
12	0819	302.76	1.48	1.05	1.05	109	98	19.8	250	572
11	0822	304.62	1.55	1.10	1.10	110	98	19.8	250	576
10	0825	306.50	1.55	1.10	1.10	111	98	19.9	250	596
9	0828	308.35	1.55	1.10	1.10	112	99	19.9	250	601

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

Corrected Sample Vol. at Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

Sample No. As-2-0

Impinger No.	Solution Used	Imp. Tip Configuration	Weight (grams)	
#1	10% H_2O_2	st	Final	897.8
			Initial	702.9
			Wt. gain	194.9
#2	10% H_2O_2	st	Final	716.7
			Initial	683.1
			Wt. gain	33.6
#3	10% H_2O_2	st	Final	686.3
			Initial	682.3
			Wt. gain	4.0
#4	0.1N NaOH	sg	Final	670.3
			Initial	671.0
			Wt. gain	-0.7 *
#5	0.1N NaOH	sg	Final	698.2
			Initial	696.2
			Wt. gain	2.0
#6	Silica gel	st	Final	706.0
			Initial	685.2
			Wt. gain	20.8

TOTAL WEIGHT GAIN OF IMPINGERS (grams) 254.6

* indicates that part of the impinger solution was entrained into the next impinger.

ORSAT ANALYSIS RESULTS

Date: _____

Time: _____

	Gas Fractional Part
CO_2	
O_2	
CO	
N_2	

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Inlet West

Date July 14, 1976 Filter No.

Sample No. As #2 Bar. Press. "Hg" 28.20 Oper. Fuchs

Meter No. E-314 Stack Press. "H_2O" -.90 Probe No. 6 ft.

Nozzle No. 3/16 Orifice Constants: a = b = PTCF 0.85

Nozzle Area 1.632×10^{-4} (ft^2) Δp 1.00 ΔH .82 (in. H_2O) K .82

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
	0555	347.47	0.19	0.16	0.16					
4	0600	348.66	0.22	0.18	0.18	112	90	3.0	250	594
4	0605	349.90	0.22	0.18	0.18	116	90	3.0	250	586
5	0610	351.70	0.45	0.37	0.37	120	91	4.5	250	608
5	0615	353.60	0.45	0.37	0.37	122	91	4.5	250	605
6	0620	355.64	0.52	0.44	0.44	124	92	5.3	250	635
6	0625	357.65	0.52	0.44	0.44	124	93	10.0	250	630
13	0630	357.65	0.22	0.18	0.18					
13	0635	358.90	0.22	0.18	0.18	118	94	12.0	250	616
13	0640	360.18	0.22	0.18	0.18	118	93	7.5	250	623
14	0645	361.70	0.48	0.40	0.40	116	93	16.8	250	636
14	0650	363.69	0.48	0.40	0.40	111	94	21.0	250	631
15	0731	363.81	0.50	0.41	0.41					
15	0736	365.81	0.50	0.41	0.41	119	95	4.3	250	656
15	0741	367.85	0.50	0.41	0.41	124	95	4.3	250	654

Total Sample Time 120 Min.

Avg. Meter Temp. 112 °F

Avg. Stack Temp. 602 °F

Corrected Sample Vol. at Meter Conditions

(42.31) x (0.9955)

(Net Vol) (D.G.M.C.F.)

42.12 ft^3

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Inlet East

Date July 14, 1976 Filter No. _____

Sample No. As #2 (Contd) Bar. Press. "Hg" _____ Oper. Fuchs

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: $\frac{a}{b}$ _____ PTCF _____

Nozzle Area _____ (ft^2) Δp _____ ΔH _____ (in. H_2O) K _____

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F	
				Desired	Actual	Inlet	Outlet				
	0801	367.85	0.27	0.22	0.22						
4	0806	369.27	0.27	0.22	0.22	123	99	3.2	250	583	
4	0811	370.65	0.27	0.27	0.22	126	99	3.2	250	581	
5	0816	372.58	0.53	0.44	0.44	130	100	4.4	250	599	
5	0821	374.65	0.53	0.44	0.44	132	100	4.5	250	596	
6	0826	376.74	0.55	0.45	0.45	133	101	4.8	250	617	
6	0831	378.86	0.56	0.47	0.47	134	102	5.1	250	632	
13	0837	378.86	0.28	0.23	0.23						
13	0842	380.30	0.28	0.23	0.23	132	105	3.8	250	531	
13	0847	381.73	0.28	0.23	0.23	134	104	3.8	250	528	
14	0852	383.66	0.49	0.405	0.405	135	105	5.0	250	573	
14	0857	385.64	0.49	0.405	0.405	137	106	5.5	250	558	
15	0902	387.71	0.53	0.44	0.44	136	106	12.1	250	587	
15	0907	389.78	0.53	0.44	0.44	131	106	16.0	250	581	STOP

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

Corrected Sample Vol. at Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

Sample No. As-2-I

Impinger No.	Solution Used	Imp. Tip Configuration	Weight (grams)
#1	10% H_2O_2	st	Final 803.1 Initial 648.1 Wt. gain 119.0
#2	10% H_2O_2	st	Final 714.4 Initial 681.4 Wt. gain 33.0
#3	10% H_2O_2	st	Final 696.7 Initial 697.9 Wt. gain -1.2 *
#4	0.1N NaOH	sg	Final 826.5 Initial 688.0 Wt. gain 138.5
#5	0.1N NaOH	sg	Final 538.0 Initial 671.8 Wt. gain -133.8 *
#6	Silica gel	st	Final 667.7 Initial 651.3 Wt. gain 16.4

TOTAL WEIGHT GAIN OF IMPINGERS (grams) 171.9

* indicates that part of the impinger solution was entrained into the next impinger.

ORSAT ANALYSIS RESULTS

Date: _____

Time: _____

	Gas Fractional Part
CO_2	
O_2	
CO	
N_2	

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 14, 1976 Filter No. _____

Sample No. As #3 Bar. Press. "Hg" 28.20 Oper. Rohlack

Meter No. E-313 Stack Press. "H_2O" 28.02 Probe No. 6 ft.

Nozzle No. 3/16 Orifice Constants: a _____ b _____ PTCF 0.85

Nozzle Area 1.632×10^{-4} (ft^2) Δp 1.35 ΔH .96 (in. H_2O) K .71

	Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
					Desired	Actual	Inlet	Outlet			
Northport (Fig.4-6)	17	1130	324.92	1.35	0.96	0.96	109	105	20.0	250	588
	17	1133	326.82	1.35	0.96	0.96	109	105	20.0	250	589
	16	1136	328.68	1.38	0.98	0.98	111	105	20.0	250	589
	16	1139	330.50	1.38	0.98	0.98	112	106	20.0	250	589
	15	1142	332.36	1.38	0.98	0.98	113	106	20.0	250	592
	15	1145	334.20	1.38	0.98	0.98	114	105	20.0	250	591
	14	1148	336.06	1.40	1.00	1.00	115	106	20.0	250	592
	13	1151	337.90	1.40	1.00	1.00	115	106	20.0	250	594
	12	1154	339.74	1.50	1.07	1.07	116	106	20.0	250	596
	11	1157	341.61	1.55	1.10	1.10	116	106	20.0	250	604
	10	1200	343.40	1.55	1.10	1.10	117	106	20.0	250	623
	9	1203	345.22	1.52	1.08	1.08	117	106	20.0	250	628
	8	1206	347.04	1.55	1.10	1.10	119	106	20.0	250	627
	7	1209	348.87	1.55	1.10	1.10	119	108	20.0	250	628
	6	1212	350.70	1.50	1.07	1.07	120	108	20.0	250	629
	5	1215	352.70	1.48	1.05	1.05	120	108	20.0	250	628
	4	1218	354.375	1.40	1.00	1.00	120	108	20.0	250	626
	3	1221	356.15	1.30	0.93	0.93	119	108	20.0	250	624

Total Sample Time 120 Min.

Avg. Meter Temp. 114 °F

Avg. Stack Temp. 610 °F

Corrected Sample Vol. at Meter Conditions

(71.65) x (1.001)

(Net Vol) (D.G.M.C.F.)

= 71.73 ft^3

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 14, 1976 Filter No. _____

Sample No. As #3 (Contd) Bar. Press. "Hg" _____ Oper. Rohlack

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: a _____ b _____ PTCF _____

Nozzle Area _____ (ft^2) Δp _____ ΔH _____ (in. H_2O) K _____

	Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
					Desired	Actual	Inlet	Outlet			
	2	1224	357.915	0.95	0.68	0.68	118	108	20.0	250	625
Westport (Fig.4-6)	1	1227	359.67				120	108	20.0	250	625
	17	1315	361.46	1.25	0.89	0.89	117	112	20.0	250	586
	17	1318	363.30	1.25	0.89	0.89	117	111	20.0	250	586
	16	1321	365.075	1.30	0.93	0.93	116	110	20.0	250	588
	16	1324	366.90	1.30	0.93	0.93	115	109	20.0	250	589
	15	1327	368.69	1.33	0.95	0.95	115	109	20.0	250	593
	15	1330	370.37	1.33	0.95	0.95	115	109	20.0	250	596
	14	1333	372.11	1.42	1.01	1.01	116	109	20.0	250	596
	13	1336	373.86	1.50	1.07	1.07	119	110	20.0	250	604
	12	1339	375.60	1.50	1.07	1.07	120	110	20.0	250	603
	11	1342	377.32	1.55	1.10	1.10	122	111	20.0	250	609
	10	1345	379.11	1.50	1.07	1.07	124	112	20.0	250	622
	9	1348	381.00	1.45	1.03	1.03	124	113	20.0	250	622
	8	1351	382.63	1.38	0.98	0.98	125	113	20.0	250	623
	7	1354	384.39	1.30	0.98	0.98	125	114	20.0	250	624
	6	1357	386.19	1.18	0.84	0.84	126	114	20.0	250	624
	5	1400	387.90	1.10	0.78	0.78	126	114	20.0	250	628

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

Corrected Sample Vol. at Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Outlet

Date July 14, 1976 Filter No. _____

Sample No. As #3 (Contd) Bar. Press. "Hg" _____ Oper. Rohlack

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: a _____ b _____ PTCF _____

Nozzle Area (ft^2) _____ Δp _____ ΔH (in. H_2O) _____ K _____

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F	
				Desired	Actual	Inlet	Outlet				
4	1403	389.70	1.10	0.78	0.78	126	114	20.0	250	628	
3	1406	391.40	1.10	0.78	0.78	125	115	20.0	250	629	
2	1409	393.07	0.95	0.68	0.68	125	116	20.0	250	630	
1	1412	394.90	0.70	0.50	0.50	124	114	20.0	250	630	
	1415	396.57									STOP

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

rected Sample Vol.
Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

Sample No. As-3-0

Impinger No.	Solution Used	Imp. Tip Configuration	Weight (grams)
#1	10% H_2O_2	st	Final - †
			Initial 681.89
			Wt. gain
#2	10% H_2O_2	st	Final 737.0
			Initial 703.6
			Wt. gain 33.4
#3	10% H_2O_2	st	Final 687.7
			Initial 684.1
			Wt. gain 3.6
#4	0.1N NaOH	sg	Final - †
			Initial 690.0
			Wt. gain
#5	0.1N NaOH	sg	Final 685.7
			Initial 684.2
			Wt. gain 1.5
#6	Silica gel	st	Final 696.0
			Initial 672.9
			Wt. gain 23.1

TOTAL WEIGHT GAIN OF IMPINGERS (grams) -

† Faulty sample

ORSAT ANALYSIS RESULTS

Date: _____

Time: _____

	Gas Fractional Part
CO_2	
O_2	
CO	
N_2	

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Inlet East

Date July 14, 1976 Filter No. _____

Sample No. As #3 Bar. Press. "Hg" 28.2 Oper. Fuchs

Meter No. E-314 Stack Press. "H_2O" -1.0 Probe No. 6 ft.

Nozzle No. 3/16 Orifice Constants: a _____ b _____ PTCF .85

Nozzle Area (ft^2) 1.632×10^{-4} Δp 1.00 ΔH (in. H_2O) .82 K .82

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet			
	1132	389.91	0.30	0.25	0.25					
13	1137	391.43	0.30	0.25	0.25	130	112	3.2	250	570
13	1142	392.96	0.30	0.25	0.25	138	112	3.2	250	561
14	1147	395.08	0.50	0.41	0.41	140	112	4.2	250	590
14	1152	396.98	0.50	0.41	0.41	141	112	4.2	250	591
15	1157	399.01	0.52	0.42	0.42	142	114	4.3	250	624
15	1202	401.10	0.52	0.42	0.42	144	114	4.3	250	636
	1205	401.10	0.25	0.21	0.21					
4	1210	402.48	0.25	0.21	0.21	142	116	3.7	250	627
4	1215	403.84	0.25	0.21	0.21	143	116	3.5	250	625
5	1221	406.29	0.54	0.45	0.45	142	116	10.0	250	641
5	1225	408.02	0.54	0.45	0.45	144	116	17.0	250	650
6	1229	409.26	0.54	0.45	0.45	132	114	23.0	250	
6	1235		0.54	0.45	0.45				250	
6	1300	409.26	0.54	0.45	0.45				250	
6	1303	410.48	0.54	0.45	0.45	136	114	4.5	250	675
6	1306	411.78	0.54	0.45	0.45	140	115	4.3	250	656

Total Sample Time 120 Min.

Avg. Meter Temp. 129 °F

Avg. Stack Temp. 639 °F

Corrected Sample Vol. at Meter Conditions

(42.63) x (0.9955)

(Net Vol) (D.G.M.C.F.)

42.32_{ft^3}

FIELD SAMPLING DATA

Plant Name Cu-Smelter Stack Name ESP Inlet West

Date July 14, 1976 Filter No. _____

Sample No. As #3 (Contd) Bar. Press. "Hg" _____ Oper. _____

Meter No. _____ Stack Press. "H_2O" _____ Probe No. _____

Nozzle No. _____ Orifice Constants: a _____ b _____ PTCF _____

Nozzle Area _____ (ft^2) Δp _____ ΔH _____ (in. H_2O) K _____

Pt.	Clock Time	Dry Gas Meter Reading	ΔP_n in. H_2O	ΔH_n in. H_2O		Dry Gas Meter Temperature		L. Vac. In. Hg Gauge	Box Temp °F	Stack Temp °F	
				Desired	Actual	Inlet	Outlet				
	1320	411.78	0.20	0.16	0.16						
13	1325	413.01	0.20	0.16	0.16	136	114	3.0	250	653	
13	1330	414.19	0.20	0.16	0.16	139	113	3.0	250	672	
14	1335	416.07	0.47	0.38	0.38	144	115				
14	1340	418.02	0.47	0.38	0.38	145	116	5.2	250	682	
15	1345	419.97	0.48	0.40	0.40	148	116	11.2	250	688	
15	1350	422.09	0.48	0.40	0.40	148	116	14.0	250	688	
4	1400	422.09	0.22	0.185	0.185						
4	1405	423.32	0.22	0.185	0.185	142	120	11.0	250	625	
4	1410	424.59	0.22	0.185	0.185	140	119	15.3	250	625	
5	1445	424.59	0.43	0.36							
5	1450	426.47	0.44	0.37	0.37	142	121	3.9	250	633	
5	1455	428.40	0.44	0.37	0.37	144	120	3.9	250	633	
6	1500	430.50	0.41	0.42	0.42	146	120	4.2	250	651	
6	1505	432.54	0.51	0.42	0.42	148	120	4.2	250	652	STOP

Total Sample Time _____ Min.

Avg. Meter Temp. _____ °F

Avg. Stack Temp. _____ °F

Corrected Sample Vol. at Meter Conditions

(_____) x (_____)

(Net Vol) (D.G.M.C.F.)

_____ ft^3

Sample No. As-3-I

Impinger No.	Solution Used	Imp. Tip Configuration	Weight (grams)	
#1	10% H_2O_2	st	Final	812.0
			Initial	697.8
			Wt. gain	114.2
#2	10% H_2O_2	st	Final	680.2
			Initial	667.3
			Wt. gain	12.9
#3	10% H_2O_2	st	Final	704.8
			Initial	678.2
			Wt. gain	26.6
#4	0.1N NaOH	sg	Final	846.2
			Initial	672.7
			Wt. gain	173.5
#5	0.1N NaOH	sg	Final	482.1
			Initial	679.8
			Wt. gain	-197.7 *
#6	Silica gel	st	Final	683.5
			Initial	668.9
			Wt. gain	14.6

TOTAL WEIGHT GAIN OF IMPINGERS (grams) 144.1

* indicates that part of the impinger solution was entrained into the next impinger.

ORSAT ANALYSIS RESULTS

Date: _____

Time: _____

	Gas Fractional Part
CO_2	
O_2	
CO	
N_2	

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TABLE OF CONVERSION FACTORS

Multiply English Unit	by Conversion	To Obtain Metric Unit
acres	0.405	hectares
acre-feet	1233.5	cubic meters
barrel, oil	158.97	liters
British Thermal Unit	0.252	kilogram-calories
British Thermal Unit/pound	0.555	kilogram calories/kilogram
cubic feet/minute	0.028	cubic meters/minute
cubic feet/second	1.7	cubic meters/minute
cubic feet	0.028	cubic meters
cubic feet	28.32	liters
cubic inches	16.39	cubic centimeters
degree Fahrenheit	0.555(°F-32) (a)	degree Centigrade
feet	0.3048	meters
gallon	3.785	liters
gallon/minute	0.0631	liters/second
horsepower	0.7457	kilowatts
inches	2.54	centimeters
inches of mercury	0.03342	atmospheres
pounds	0.454	kilograms
million gallons/day	3785	cubic meters/day
mile	1.609	kilometer
pound/square inch (gauge)	(0.06805 psig+1) (a)	atmospheres (absolute)
square feet	0.0929	square meters
square inches	6.452	square centimeters
tons (short)	0.907	metric tons (1000 kilograms)
yard	0.9144	meters

(a) Actual conversion, not a multiplier.